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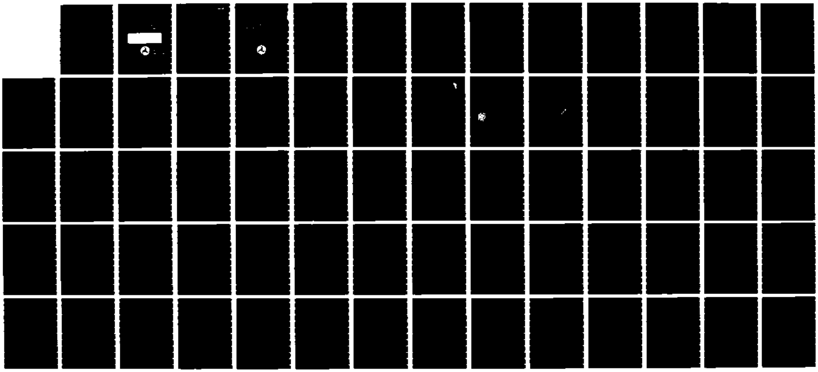

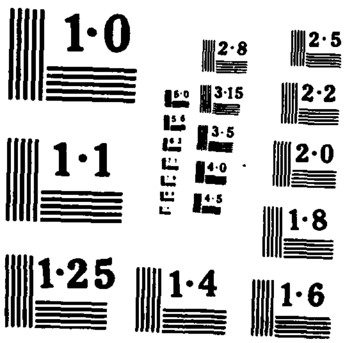
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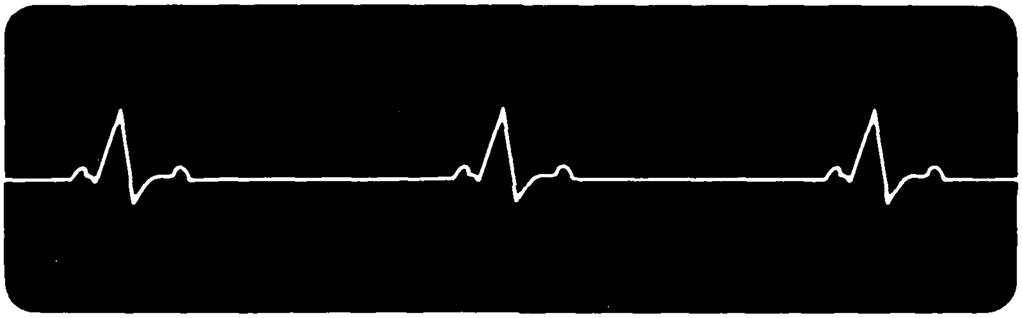
CAORF 60-7805-01

CAORF TECHNICAL REPORT
SIMULATION EXPERIMENT

APPLICATION OF HEART RATE MEASUREMENTS TO MARITIME RESEARCH SIMULATOR

AD-A169 988



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MARCH 1986

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16. Abstracts

An experiment was performed on the Ship Simulator of the Computer Aided Operations Research Facility (CAORF) to determine the feasibility of relating the instantaneous heart rates of test subjects with the nature of their on-bridge activity at the time of measurement. It was found that experienced mariners confronted with potential collision situations on the simulator or with difficult maneuvering problems in restricted waters generally experienced elevated heart rates indicative of increased cognitive and emotional arousal. It was also found thatvariability of heart rate appears to be useful in differentiating workload demands imposed on the mariner by different navigation conditions.

The fact that physiological reactions were observed to occur on the simulator in situations which would be expected to be emotionally arousing indicates, first, that the simulator is recreating, to a degree, the real-world atmosphere, and second, that heart rate measurements can be usefully applied in future research to detect emotional and or cognitive levels of arousal. keywords:

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CAORF TECHNICAL REPORT
SIMULATION EXPERIMENT

APPLICATION OF HEART RATE MEASUREMENTS TO MARITIME RESEARCH SIMULATOR

By

Elliot Wald, Ph.D.
CAORF Research Staff

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MARCH 1986

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CHAPTER 1

BACKGROUND TO EXPERIMENT

1.1 INTRODUCTION

Simulators have wide usage in many industries for improving skills of personnel or for research into questions involving human reactions to various controlled conditions. Research applications require that real-world conditions be very accurately simulated so that reactions measured on the simulator will closely parallel those expected in the real world. One example of a research system is the Ship Maneuvering Simulator at the U. S. Department of Transportation's Computer Aided Operations Research Facility (CAORF) located at the National Maritime Research Center, Kings Point, New York. The CAORF research simulator is capable of accurately duplicating maritime conditions, including ship hydrodynamic and aerodynamic charactersitics, port and channel physical dimensions, wind, current, and tug forces, routine or critical navigation obstructions or hazards, and emergency stations such as propulsion and rudder failures.

Because it is essential that test subjects exposed to simulated conditions respond to them in the same manner as they would in the real world, the question of comparability between real-world and simulator performance was investigated during the CAORF development program. An independent study* compared performance at CAORF with performance at sea. Study personnel rode numerous ships at sea and collected behavioral performance data under a variety of actual conditions. Closely matched test situations were implemented and corresponding data were collected at CAORF. A very high degree of correspondence was found, indicating that subjects' performance under simulated conditions is comparable to performance under real-world conditions.

The data alluded to in the aforementioned CAORF validation study focused only on behavioral performance. It is highly desirable that other measures be obtained to provide cross-validation for existing data.

Many of the applications of the CAORF simulator involve situations that pose a threat of danger i.e., novel vessel and/or port conditions, varied navigational conditions including extreme weather and sea conditions, sudden equipment failure, etc. If such simulated conditions are reacted to in a manner comparable to such occurrences in the real world, one would expect not only comparability in behavioral responses but also in certain characteristic physiological reactions.

*"Validation of Mate Behavior at CAORF" Report Number 90-7801-01

It has been widely accepted that the autonomic nervous system, including the sensory and motor nerves serving the heart, glands, and smooth muscles of the viscera, responds in a distinct way to any emotion-provoking stimulus. It is generally accepted that (emotional) arousal can be measured directly by the psychophysiological measures that reflect autonomic nervous system activity. Included in these are electrodermal measures (skin conductance and skin potential) and measures of the circulatory system (heart rate, blood pressure, and vasomotor responses). For the present report, this psychophysiological response to environmental stimuli that the individual perceives as representing actual or potential threat, will be defined as a stress reaction.

1.2 LITERATURE REVIEW: HEART RATE MEASUREMENTS AS INDICATORS OF PSYCHOLOGICAL STATES

Of the various autonomic nervous system responses that can be measured directly, those of the circulatory system (ECG, heart rate and sinus arrhythmia) have been utilized most frequently by researchers. Conditions under which subjects' heart rates have been assessed range from real-world stress conditions to laboratory tests of cognitive and perceptual motor skills.

A number of studies have investigated the heart rates of pilots in both real-world and simulated flight conditions. A study by Teshchinskaza (1974) utilized the monitoring of heart rate in pilots during simulated flight in a trainer to evaluate periods of stress. His results indicate that variations in heart rate differentiated normal and complex emergency situations, and that variations in heart rate were due primarily to nervousness and emotional stress and to a lesser degree to physical stress. Melton (1971) recorded heart rate in pilots flying cross-country flights and found rates significantly higher as compared with rates elicited during other flight activities. Several investigators (Roman, Older, and Janec, 1967; Rasmussen 1970; Roscoe, 1978) have noted increases in physiological activity, notably heart rate, which occur in pilots during flight and especially during takeoffs and landings. For example, it has been clearly demonstrated that pilots' heart rates increase during the landing approach and reach a peak at or just before touchdown. The work of Roscoe indicates that this increase in heart rate is attributable to the physical workload demands of landing the aircraft rather than emotional stress.

Heart rates, as well as other physiological reactions, were monitored in the Apollo 11 astronauts during extra-vehicular activity on the lunar surface (Berry, 1970). Moderate tachycardia (abnormal rapidity of the heartbeat, usually in excess of 100 bpm) of 120 bpm was recorded during these exercises. Additionally, rates as high as 140-160 bpm were recorded for brief periods of time in the commander of the mission.

A considerable amount of work involving heart rate monitoring has been carried out with parachutists. A study by Fenz and Epstein (1967) monitored heart rate up to airplane egress and then again directly after ground impact, but not during the fall. They observed tachycardia of 145 bpm in novices prior to the jump and 110 bpm in experienced jumpers.

With the development of telemetry systems, a number of investigators have recorded parachutists' heart rates throughout the jump experience. Reid (1971) and Reid, Doerr and

Terry (1971) determined that parachutists exhibit heart rate profiles that are double peaked, with the highest values near parachute deployment, 157 bpm, and second to highest rates near landing, 155 bpm, compared with baseline values of 77 bpm one hour prior to the jump. Comparable results were found by Renemann, Beckhove and Roskamm (1970). They report a steady increase in parachutists' heart rates from egress to canopy deployment with occasional rates as high as 200 bpm. Similarly high rates were observed in free-fall parachuting by Schane and Stinde (1968).

The air traffic control profession has traditionally been associated with high stress and mental demand. There have been several studies using physiological measurements seeking an empirical assessment of the stress levels in air traffic controllers. Two studies by Melton, Smith, McKenzie, Wicks and Saldivar (1976, 1977) investigated stress via heart rate monitoring and urine biochemical assay in air traffic personnel in low-density towers and flight service stations. Both measures indicated on-duty arousal in air traffic controllers both physiologically and psychologically. Such arousal was within physiologically normal limits and was generally low psychologically compared with other high-density traffic facilities that had previously been studied.

Rohmert and Laurig (1977) found a significant correlation between heart rate as a parameter of stress and the number of planes controlled by the subject. Furthermore, a strong correlation was evident between heart rate and a subjective report of the difficulty of the air traffic situation. The authors take their data to support the assumption that heart rate is a valid indicator of the level of stress of a subject.

Melton et al. (1976) used heart rate monitoring to evaluate stress levels in air traffic controllers before and after the installation of an Automated Radar Terminal System, a supposed aid to traffic control. They found that heart rates of controllers on duty or at rest scarcely changed from before to after the installation of the system. The indications of the heart rate data were corroborated by the results of a state-trait anxiety inventory (paper and pencil test) which indicated no change in work-related anxiety levels of controllers with the installation of the Automated Radar System.

Recent studies have indicated that heart rate is a valid indicator of vigilance and mental work as well as the level of stress experienced by the subject. These findings have emerged primarily from laboratory work but are also supported by real-world data.

Research has indicated that a part of an individual's orienting response to any new stimulus may be an increase in heart rate (Germana & Klein, 1968). The increase in heart rate is not necessarily related to the arousal mechanism well documented by Magoun (1963) and others. A novel or rarely experienced stimulus or event frequently produces an increase in heart rate; when the event becomes known and routine the heart rate may fall (Dean, 1966).

Heart rate has furthermore been found to react differently if an individual is actively processing versus passively receiving information from his environment. Studies by Lacey and Lacey (1974) indicate that thinking is accompanied by heart rate increase while attention is accompanied by heart rate decrease. In a similar vein Obrist (1976) distinguishes between active and passive coping by an individual with his environment. Obrist found that

if a subject considers himself personally involved in survival or if he is excluding environmental stimuli while performing arithmetic or mental work, heart rate increases. Heart rate was observed to decrease when attention is directed to the environment without a sense of involvement by the subject. Obrist's interpretation was supported in a study by Carriers and Fite (1977). They found that cardiac deceleration accompanies attention to the external environment while cardiac acceleration accompanies motivated inattention.

The evidence of a relation between heart rate and attention has lead to studies of vigilance. Studies by Innes (1973) and Coons (1977) both demonstrated strong correlation relationships between heart rate and vigilance states in subjects.

A growing body of recent research has investigated the relationship between heart rate, more specifically the regularity or irregularity of heart rate as reflected in sinus arrhythmia, and subject's mental workload. Sinus arrhythmia, momentary irregularity in the heart rate pattern of up to ten or fifteen beats per minute, has been suggested as a convenient and useful measure of mental load. The chief support for this suggestion has come from the work of Kalsbeek and his colleagues (Kalsbeek and Ettema, 1963, Kalsbeek 1967, Kalsbeek, 1971). The basic idea underlying Kalsbeek's research is that the imposition of a physical workload causes an increase in the heart rate and a decrease in its variability from values found with the subject at rest. However, imposing a largely mental load does not apparently change heart rate from its resting level but does reduce its variability. Thus it is suggested that a change in heart rate variability (i.e. sinus arrhythmia) is monotonically related to the level of mental load (Kalsbeek, 1967), at least for situations where the physical load is low. Opmeer (1973) has shown that for conditions of high physical load, sinus arrhythmia will not separate different levels of mental load.

The sensitivity of sinus arrhythmia as a measure of mental load is well illustrated in the 1965 study of Kalsbeck and Ettema. They studied the suppression of sinus arrhythmia as an objective measure or whether a subject really listened to, or only heard, what was read to him. To accomplish this the first part of a Spanish text was read to a subject (sitting at rest) who did not know the language. The subject was not instructed to listen or pay attention. The second part of the text was then read and the subject was directed to count the number of times the article "los" was used. In this way an attempt was made to introduce the difference between listening and hearing experimentally. Significant differences in sinus arrhythmia were found between the rest/hearing and the listening conditions.

In a 1974 study by Boyce, physical and mental loads were varied independently. The results indicate that sinus arrhythmia does decrease with an increase in mental load, adding further support for its use as an objective measure of mental workload.

Thus, a substantive literature exists documenting the validity and utility of heart rate and variations in heart rate as objective measurement of emotional arousal and both physical and mental workload in human subjects. On this basis, the following study was undertaken at CAORF.

CHAPTER 2

EXPERIMENT METHODOLOGY

2.1 TEST SUBJECTS

A total of ten subjects was used in this experiment. All ten subjects are ships captains including six who are also New York-Sandy Hook pilots.

2.2 HEART-RATE-MEASURING APPARATUS

A telemetry system measured ECG (electrocardiogram) from a test subject on the CAORF bridge and transmitted the signal to a strip chart recorder located at the Human Factors Monitoring Station. The strip chart recorder displayed the detailed heart waveform (see Figure 2-1) and either the instantaneous or the average value of heart rate, as selected by the experimenter.

The system is comprised of the following equipment (Block diagram—Figure 2-2)

1. Hewlett-Packard Telemetry Transmitter Model 78100A
2. Hewlett-Packard Receiver Model 78101A
3. Hewlett-Packard Four-channel Strip Chart Recorder Model 7414A
4. Hewlett-Packard Rate Computer Model 8812A

The transmitter is 5 inches × 3 inches × 1 inch and weighs 10 ounces. Each test subject wore the transmitter in a small pouch supported by a belt around his waist. Each subject was connected to the transmitter by placing three self-adhesive electrodes on his chest in a

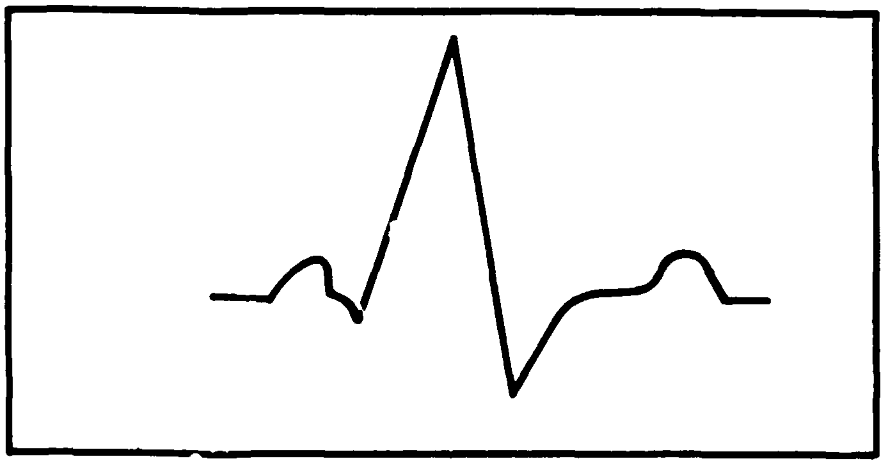

Figure 2-1. Heart Waveform

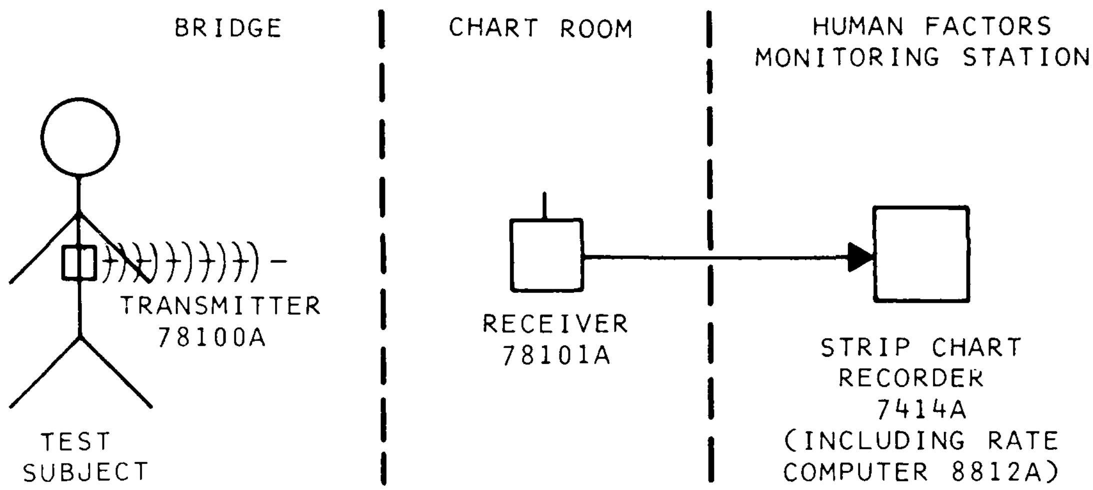

Figure 2-2. Block Diagram of Telemetry System

standard configuration, and attaching the interconnecting cable from the electrodes to the transmitter. All subjects reported that they acclimated to the electrode/transmitter assembly within a few minutes and that it neither hindered nor detracted from their performance. The electrocardiogram signals generated by the subjects were transmitted to a receiver in a chart room adjacent to the bridge and displayed on the strip chart recorder at the Human Factors Monitoring Station.

2.3 EXPERIMENT PROCEDURE

This experiment involved three distinct scenarios which are described below.

2.3.1 Collision Avoidance — Open Sea

Two captains participated in this phase of the experiment. Prior to any simulator experience, both subjects were given a general indoctrination to the CAORF facility. They were then instrumented with ECG electrodes and given a brief explanation of the telemetry monitoring system. Heart rate data acquisition began at this point and continued through all simulator runs and also off-bridge before and after simulation periods.

During preliminary data collection, it was determined that one subject was taking a weight control medication. This invalidated his participation in the experiment due to the medication's possible influence on heart rate.

The second subject's simulator experience began with a run designed to provide familiarization experience with the CAORF bridge and the handling characteristics of the 80,000 DWT tanker simulated at CAORF. He was asked to maintain a course through a prescribed channel, as illustrated in Figure 2-3.

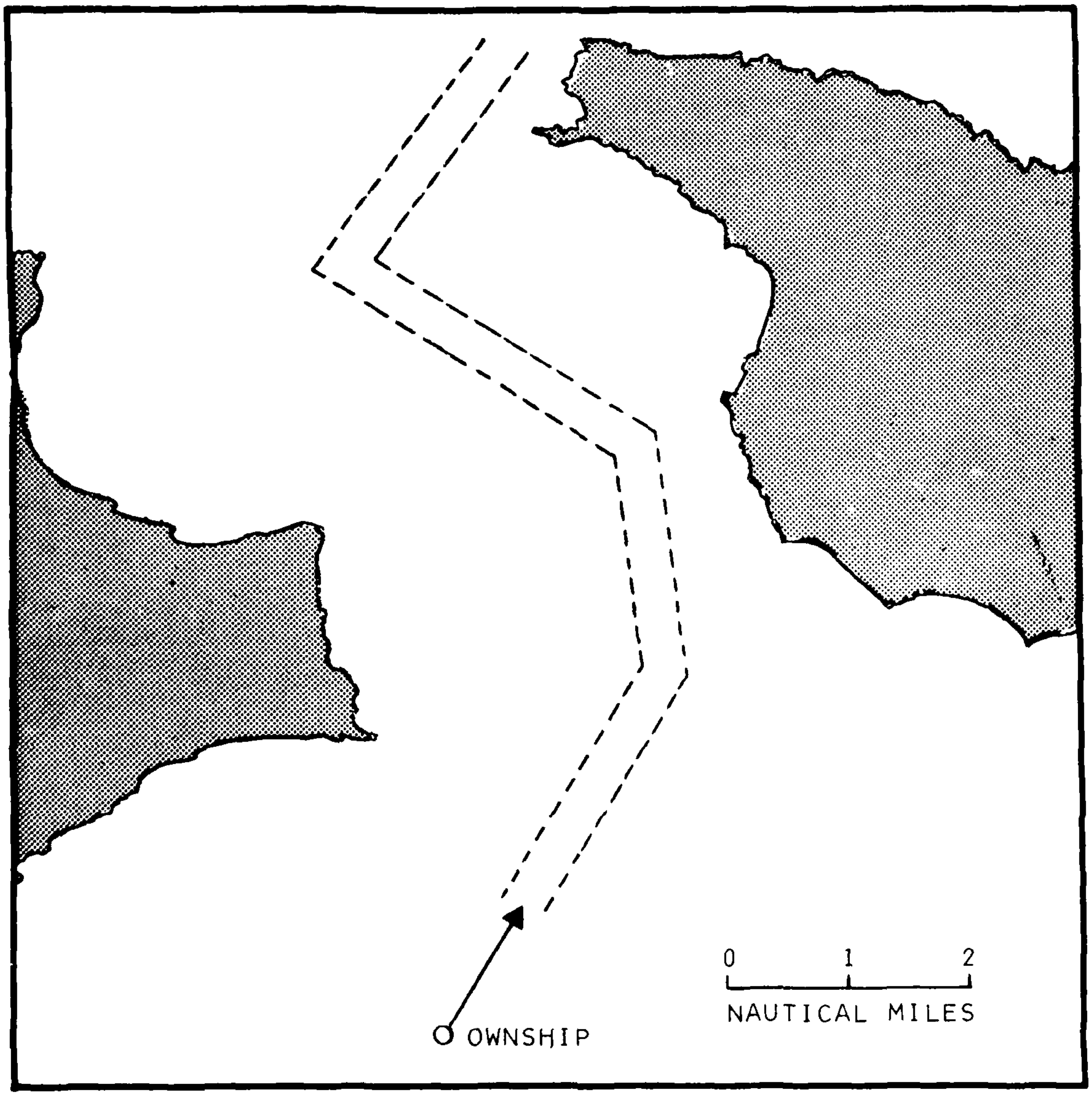

Figure 2-3. Familiarization Run Course for Collision Avoidance – Open Sea

Following this initial familiarization experience were three collision avoidance problems. The first vessel encounter situation/scenario consisted of two target vessels and is illustrated in Figure 2-4. The second and third scenarios consisted of four and five target vessels, respectively, in the encounter situations (Figures 2-5 and 2-6).

Prior to each experiment run, the subject was briefed as to ownship's heading. He was told to maintain this heading but to take whatever action was necessary to deal with any traffic encountered, and to return to the initial heading as soon as possible. Limited visibility conditions of 1/2 mile were established in each run with normal wind and current conditions. The subject had a conventional radar system with which to navigate. Heart rate data were collected through all experiment runs.

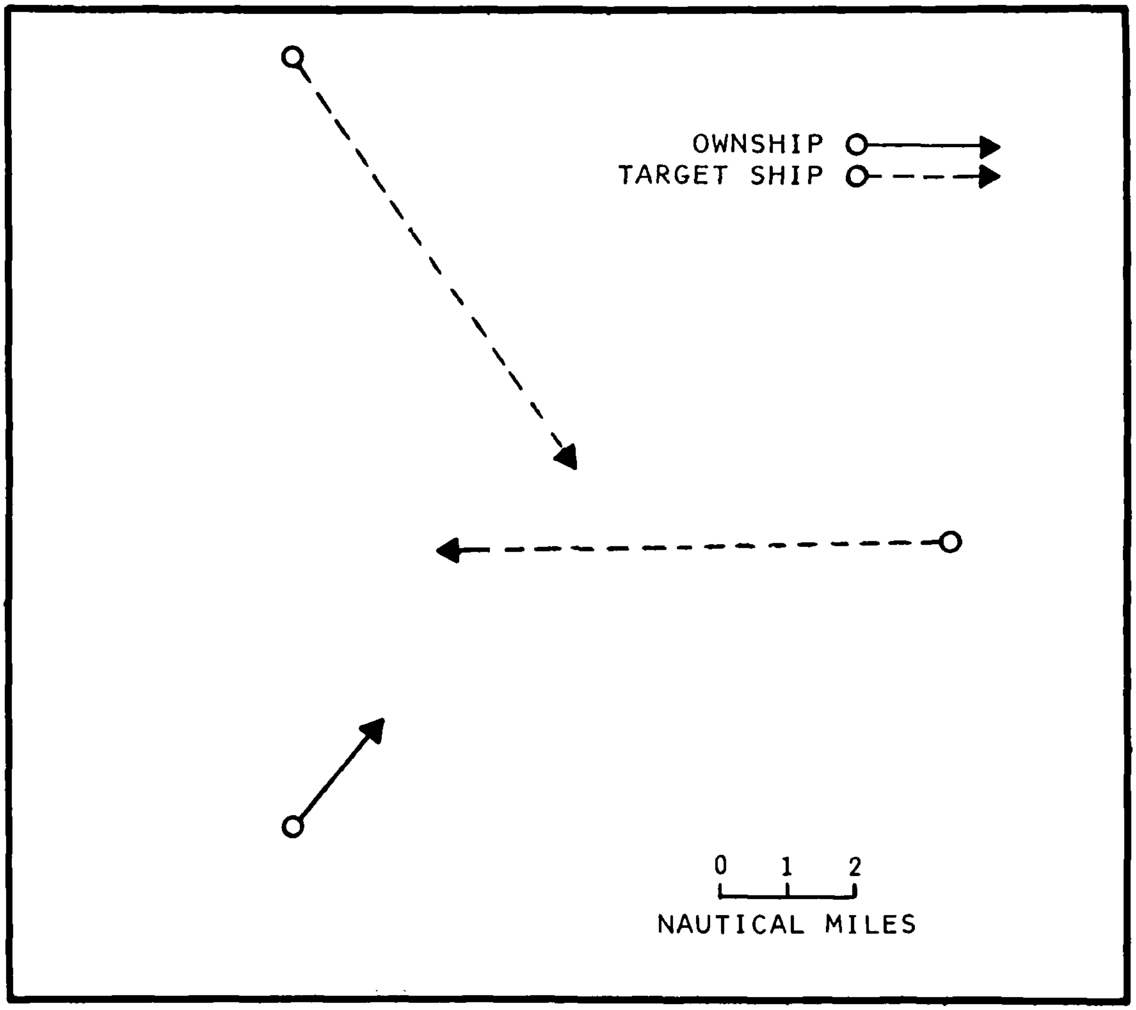

Figure 2-4. Scenario 1: Two-Ship Encounter in Open Sea

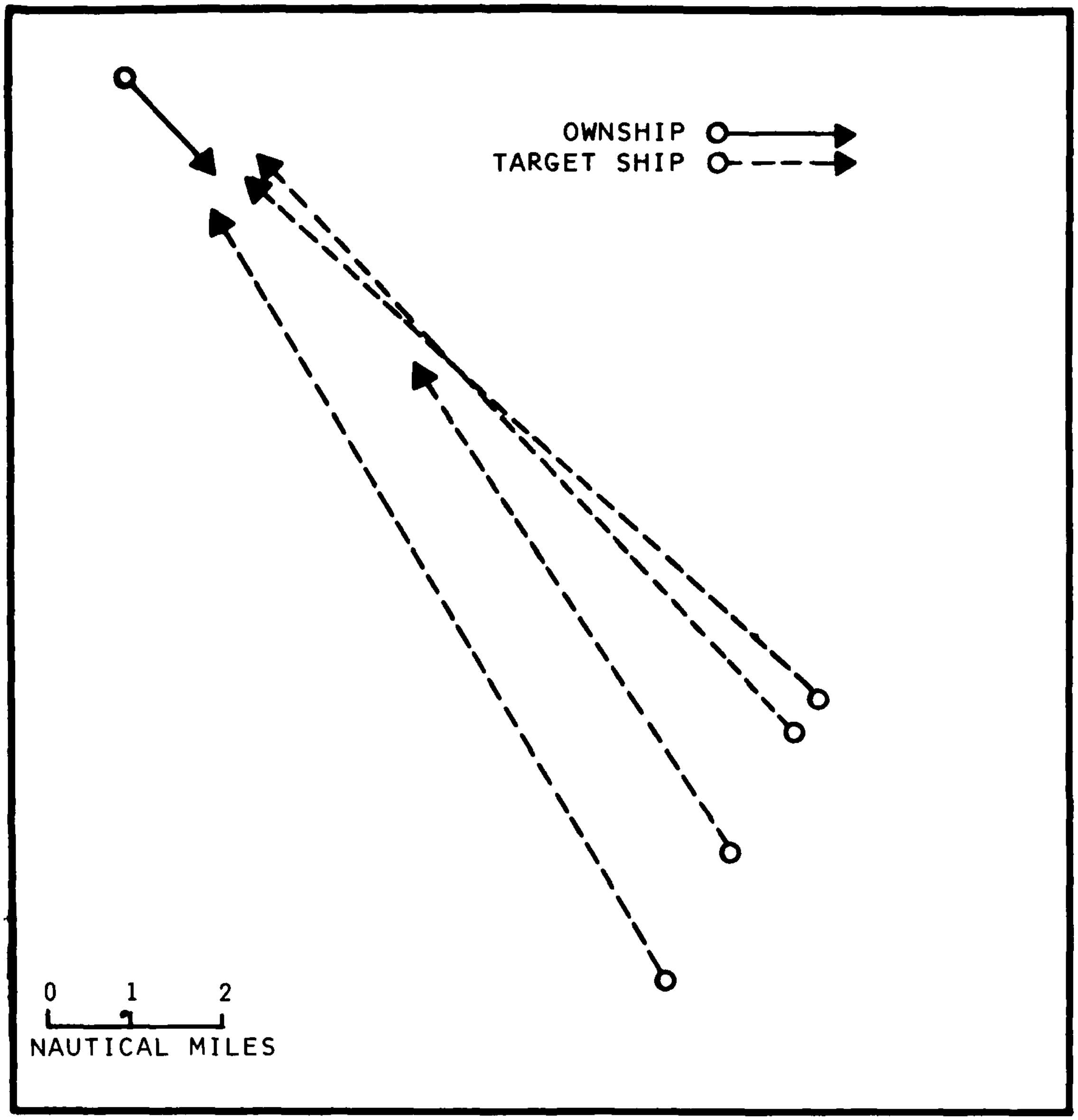

Figure 2-5. Scenario 2: Four-Ship Encounter in Open Sea

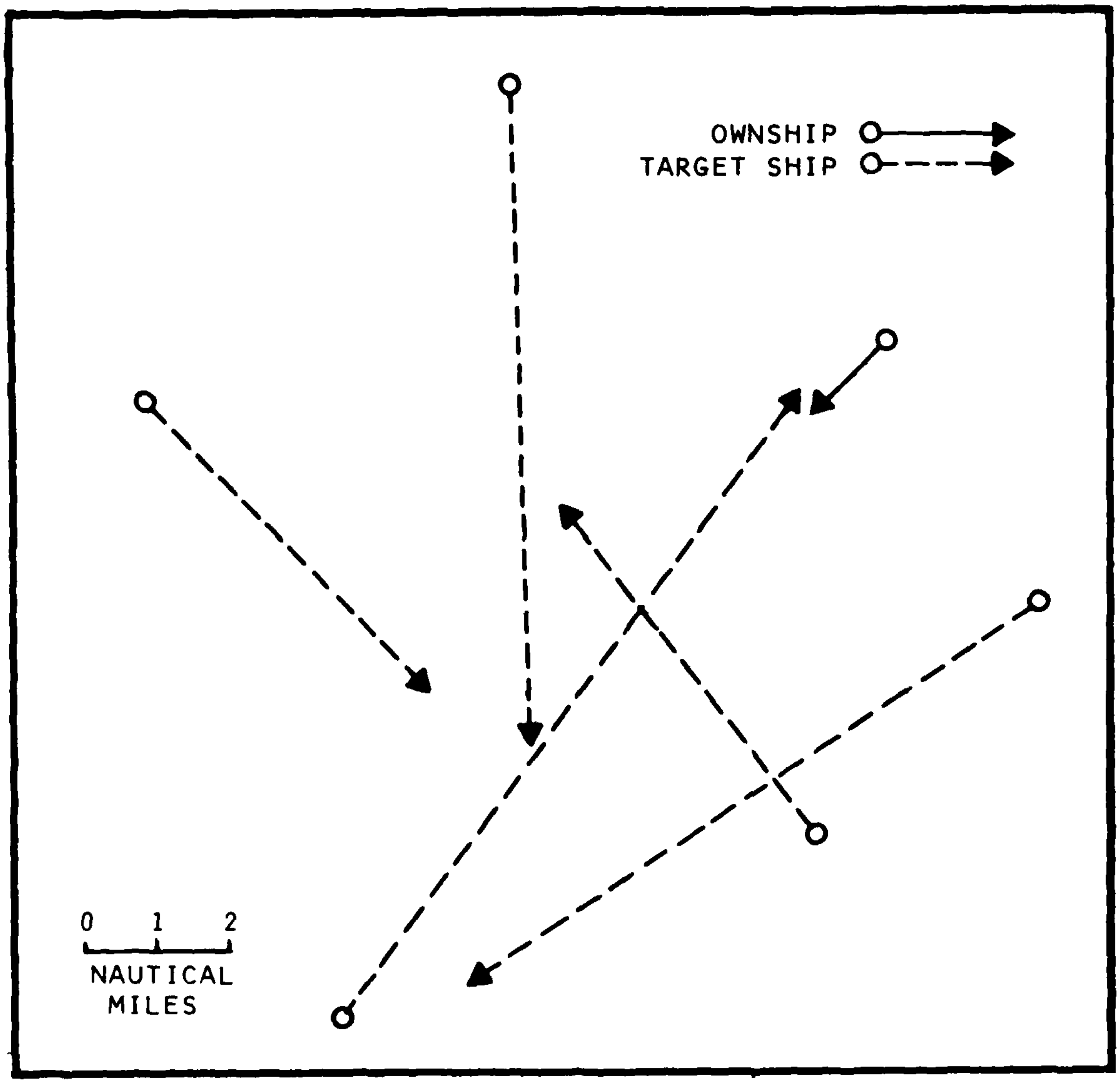

Figure 2-6. Scenario 3: Five-Ship Encounter in Open Sea

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2.3.2 Collision Avoidance in Restricted Waters

Two captains participated in this phase of the experiment. As with the subjects in collision avoidance in open sea, they were given a general indoctrination to CAORF and instrumented for ECG data collection, with its associated explanation.

The procedures followed in this phase of the study were essentially a replication of an earlier study performed at CAORF (Hayes, 1978) with the addition of heart rate monitoring.

Prior to any experimental manipulation, both subjects were provided with approximately eight hours of familiarization training consisting of both on-bridge and off-bridge experience. During this familiarization training one captain received instruction in the use of a PAD-type collision avoidance system (CAS) with a navigation option, and then hands-on experience using this system. The second subject used a conventional radar system during all phases of familiarization training.

During all on-bridge periods of familiarization training, both subjects were instrumented with ECG electrodes and the telemetry transmitter. ECG data were collected during part of each run to establish subjects' heart rate baseline.

The final phase of training for both subjects involved a limited visibility run through a restricted course with a vessel following at constant speed, 1/2 mile behind ownship. Each subject utilized his respective navigation system in this exercise, i.e. conventional radar or PAD-type CAS with a navigation option. Heart rate data were collected throughout this exercise.

Experimental testing involved exposing the subjects to each of four scenarios. All scenarios took place in a fictitious area described as "International Harbor — approach to Pilot Station from Sea", on a chart provided to the subjects. Visibility was set at 1/2 mile with conditions of moderate wind and current and ownship operating at half speed (7 knots) under bridge control. Subjects were instructed to maintain course and speed unless they perceived that a maneuver was necessary to avoid any traffic condition that arises. As in familiarization training, each subject employed his respective navigation system exclusively. The four experimental scenarios are depicted in Figures 2-7 through 2-10 with the accompanying description.

The final experience of the subjects in this phase of the experiment was an open sea collision avoidance situation consisting of an encounter with five target vessels (see Figure 2-6). The radar/CAS distinction between subjects was suspended for this run and both subjects used the conventional radar system to navigate. Heart rate data were collected during all experimental runs of this phase of the study.

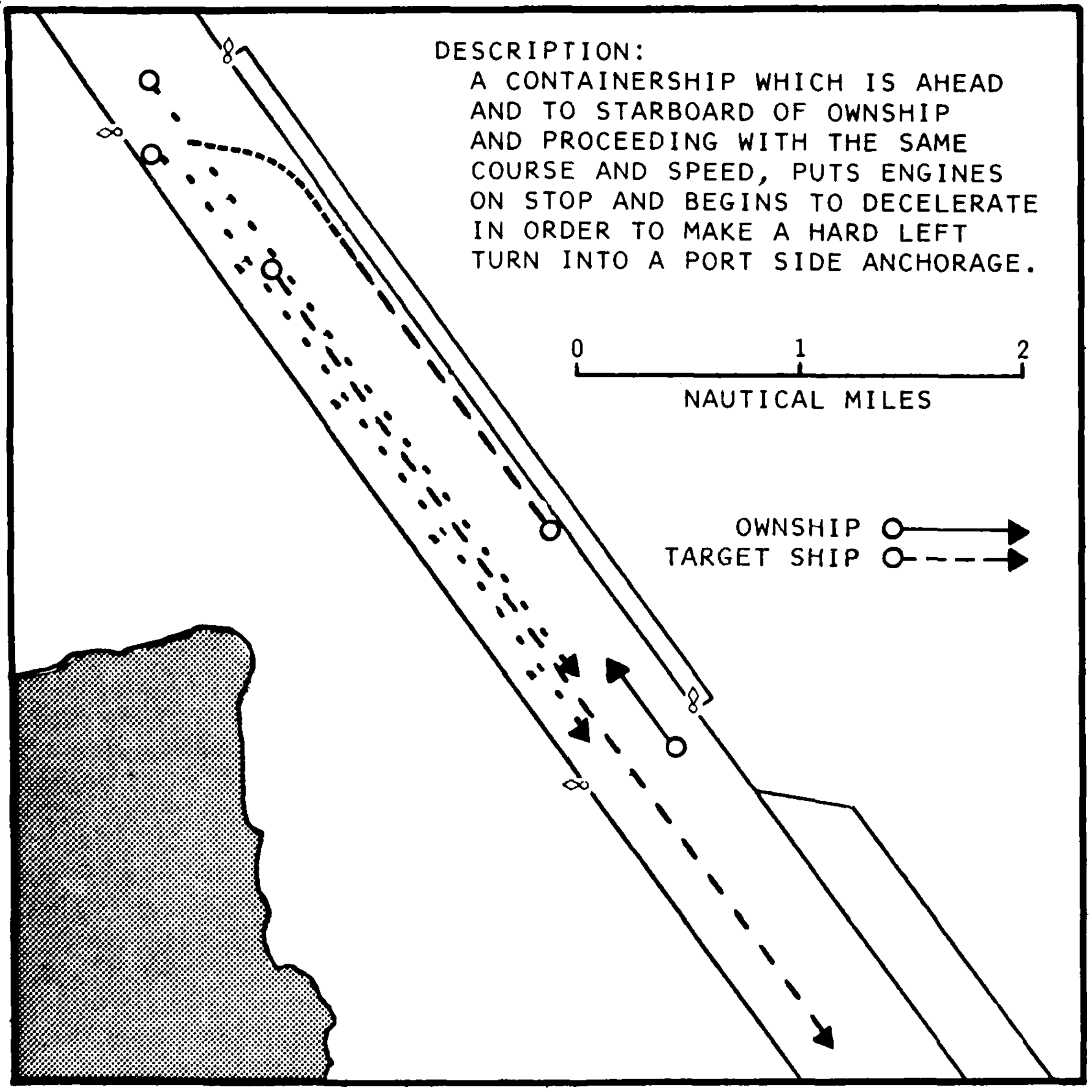

Figure 2-7. Scenario 4: Potential Collision with a Containership Slowing and Turning Across Ownship's Path

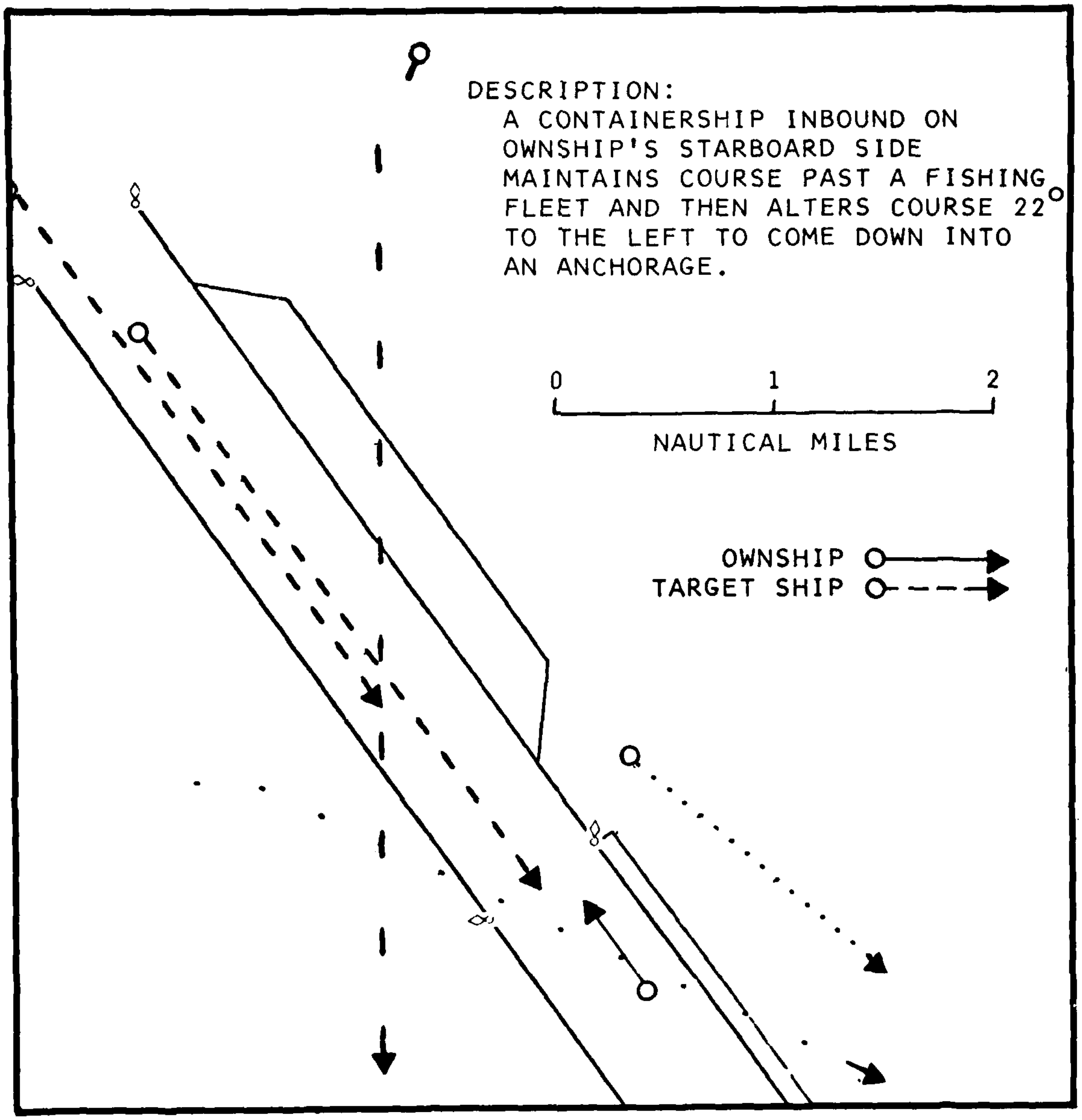

Figure 2-8. Scenario 5: Potential Collision with a Containership Crossing the Channel

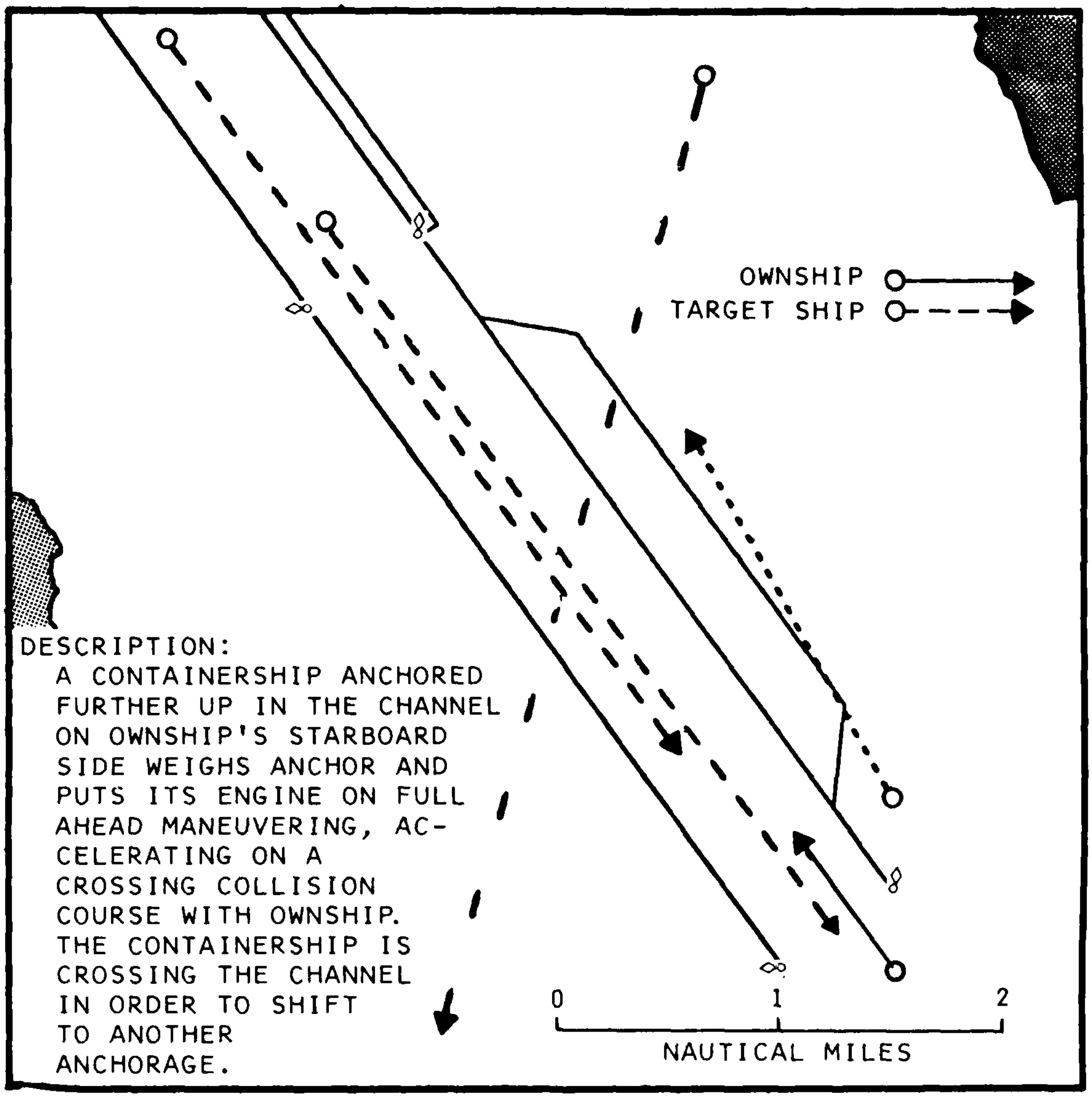

Figure 2-9. Scenario 6: Potential Collision with an Accelerating Containership Crossing the Channel

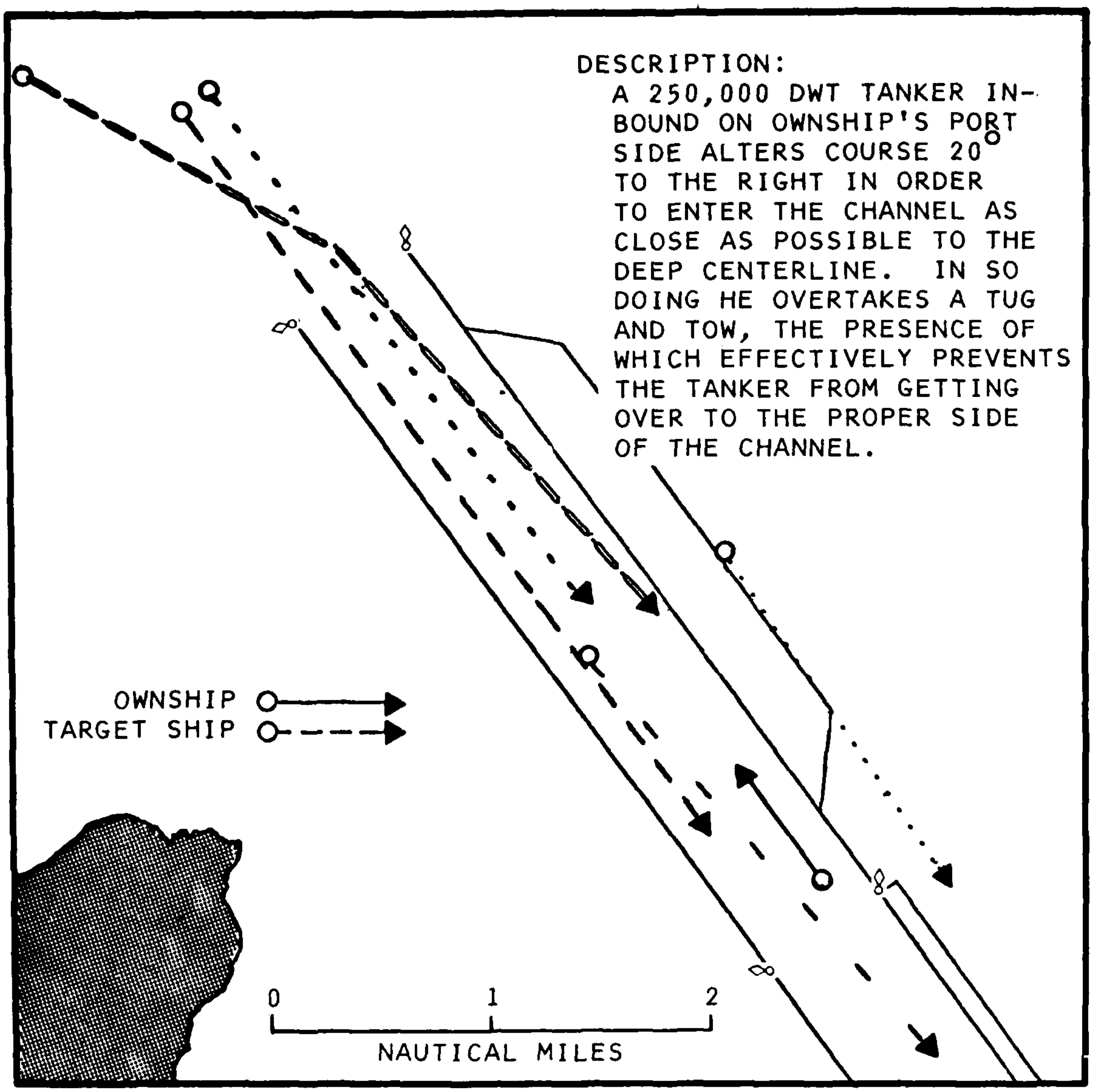

Figure 2-10. Scenario 7: Potential Collision with a Tanker on the Wrong Side of the Channel

2.3.3 New York Harbor

Six Sandy Hook pilots participated in this phase of the experiment. These subjects had had prior experience at CAORF and required little if any briefing about the facility. They were instrumented with ECG electrodes and given a brief explanation of the telemetry monitoring system.

Each subject, in one or more runs through New York Harbor, navigated a simulated model of a containership. The run began south of the Verrazano Narrows Bridge, progressing past the Constable Hook Range, through the Kill Van Kull around Bergen Point, and terminating in Port Elizabeth (Figure 2–11). During all runs, the pilots received and transmitted normal bridge-to-bridge communications. In certain runs, normal bridge-to-bridge communications were supplemented with New York Vessel Traffic Service (VTS) communications. Certain of the subjects experienced unlimited and limited (3/4 mile) visibility conditions on different runs. Heart rate data were collected during all runs.

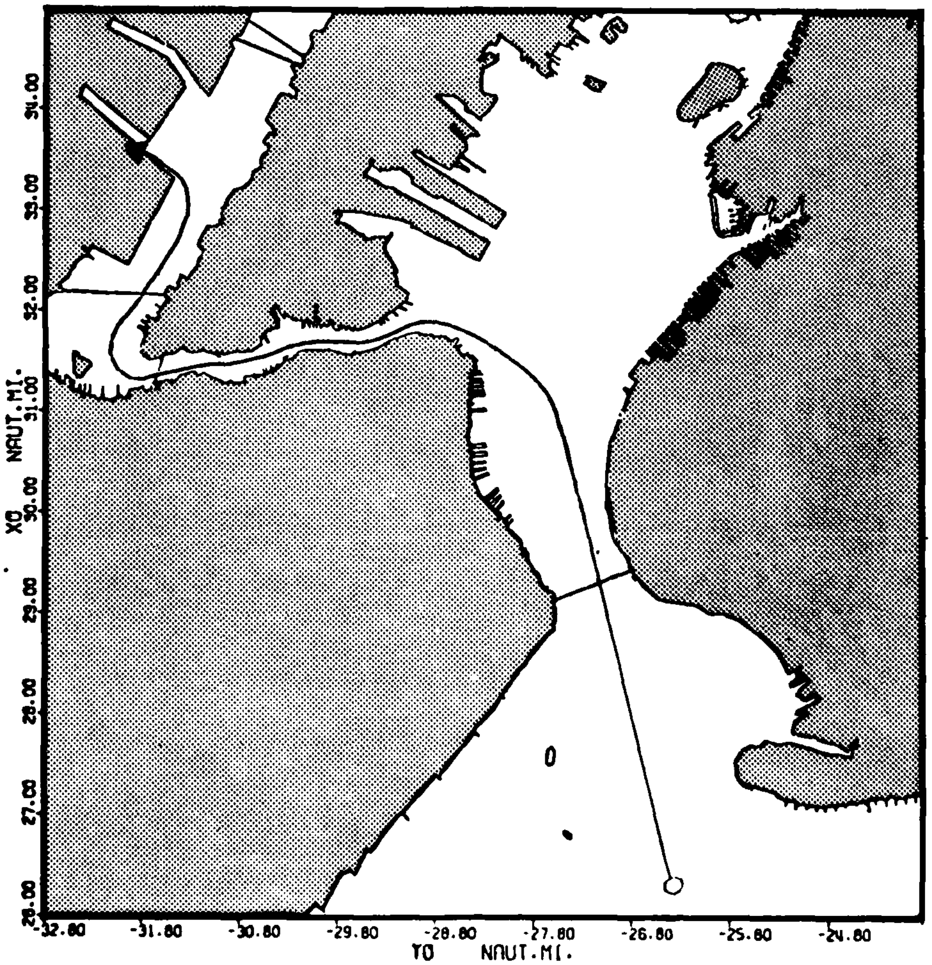

Figure 2-11. Typical Course Through New York Harbor

CHAPTER 3

RESULTS AND DISCUSSION

3.1 HEART RATE MEASURES

Two measurements were collected during the course of this experiment. Heart rate was computed for all subjects during all experiment conditions. Computation of heart rate involved the breakdown of the real time of the experimental runs into successive 5-second intervals. Mean heart rate was then computed across the 12 intervals of each minute of an experiment run.

Sinus arrhythmia was computed for selected subjects in certain of the experiment conditions. Sinus arrhythmia is a measure of the regularity of heart rate. It is computed as a variability measure of instantaneous heart rate for a defined period of time. For example, an individual's heart rate over a 1-minute period may average 70 bpm; however, from instant to instant, the heart rate may be as much as 10 to 15 beats per minute above or below this average. By computing a measure of variability (standard deviation for example), one can determine if heart rate is stable and regular for that period of time or whether it is unstable or irregular.

3.2 RESULTS FROM COLLISION AVOIDANCE IN OPEN SEA SCENARIOS

Average heart rate was computed for the subject participating in this phase of the experiment. Figure 3-1 depicts the course followed by Subject 1 through a channel designated for a familiarization run. Figure 3-2 illustrates his mean heart rate prior to, during, and following this run on a minute-by-minute basis. The subject's rate was elevated during the run in comparision to rates before and after the run. Judging these elevated rates against the pre-run rates, which occurred prior to subsequent runs for this subject (see Figures 3-4, 3-6, and 3-8), one can infer that these elevated rates represent arousal in the subject that might have been due to a "first experimental experience" rather than being attributable to the navigation demands of the scenario.

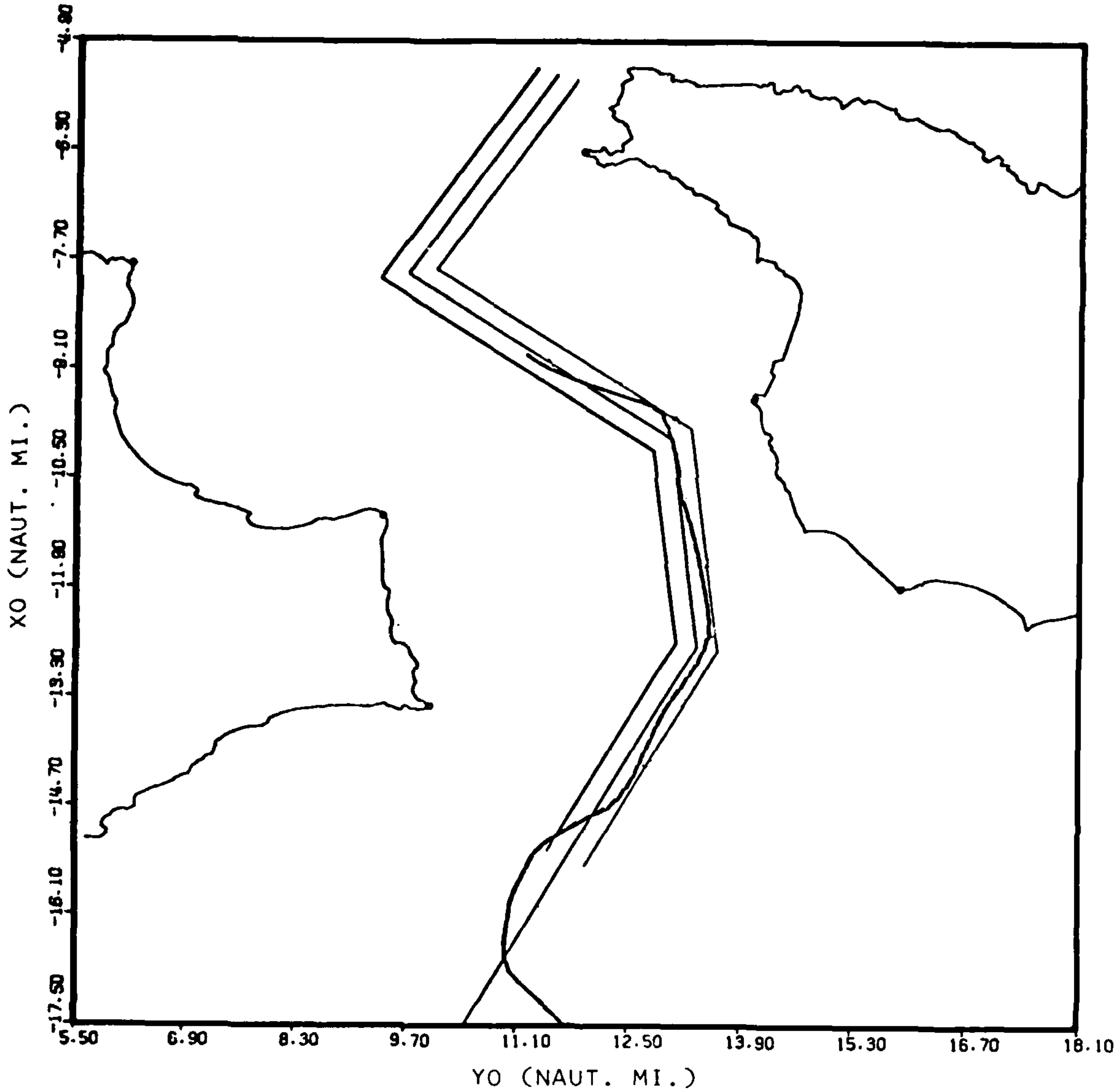

Figure 3-1. Subject 1's Course During the Familiarization Run

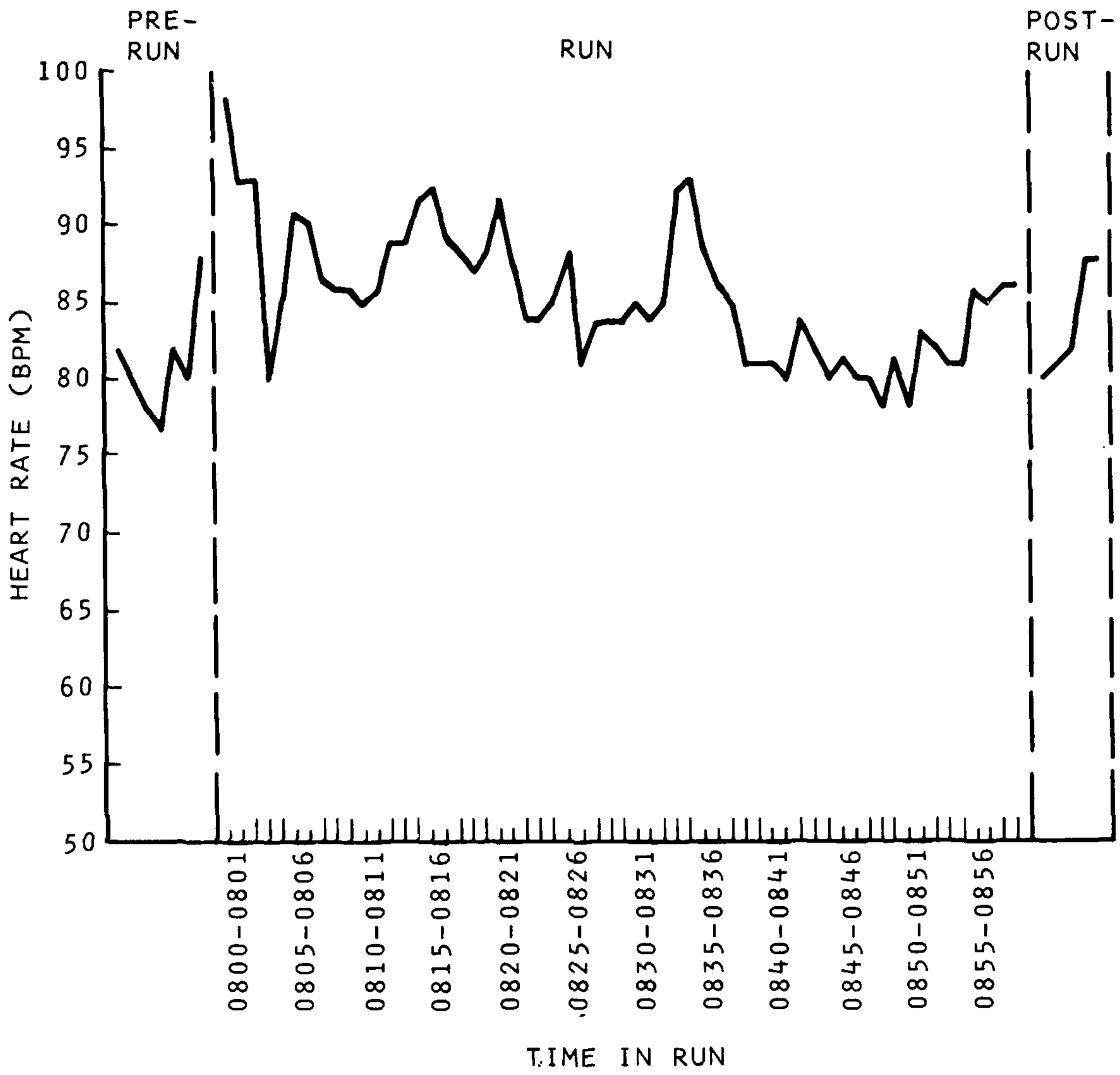

Figure 3-2. Subject 1's Heart Rate During the Familiarization Run

Figure 3-3 depicts Subject 1's progress through an encounter with two target vessels. Figure 3-4 indicates that his heart rate during this run averaged about 75 beats per minute throughout the entire run with no notable periods of elevation.

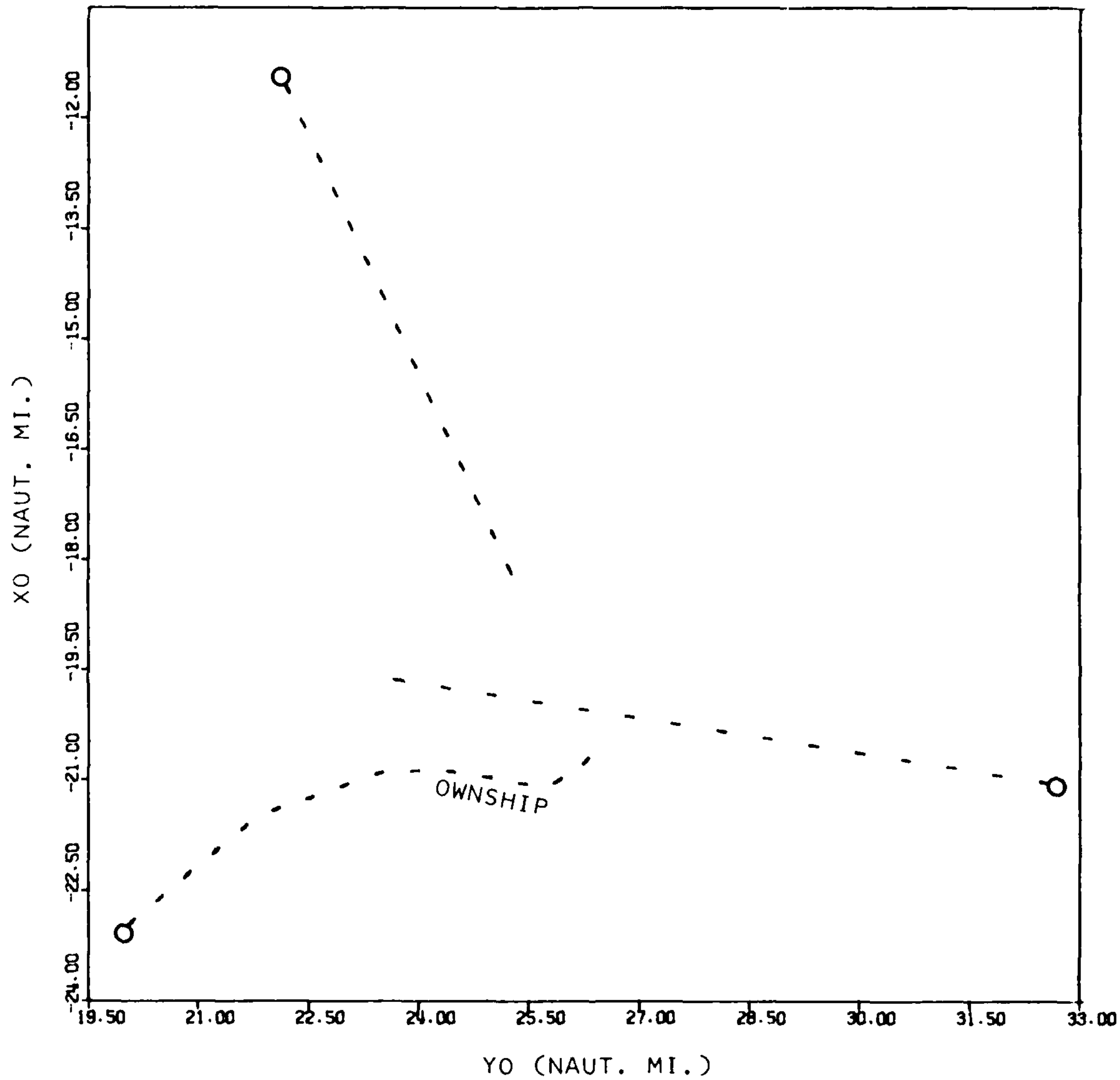

Figure 3-3. Subject 1's Course in the Two-Ship Encounter of Scenario 1

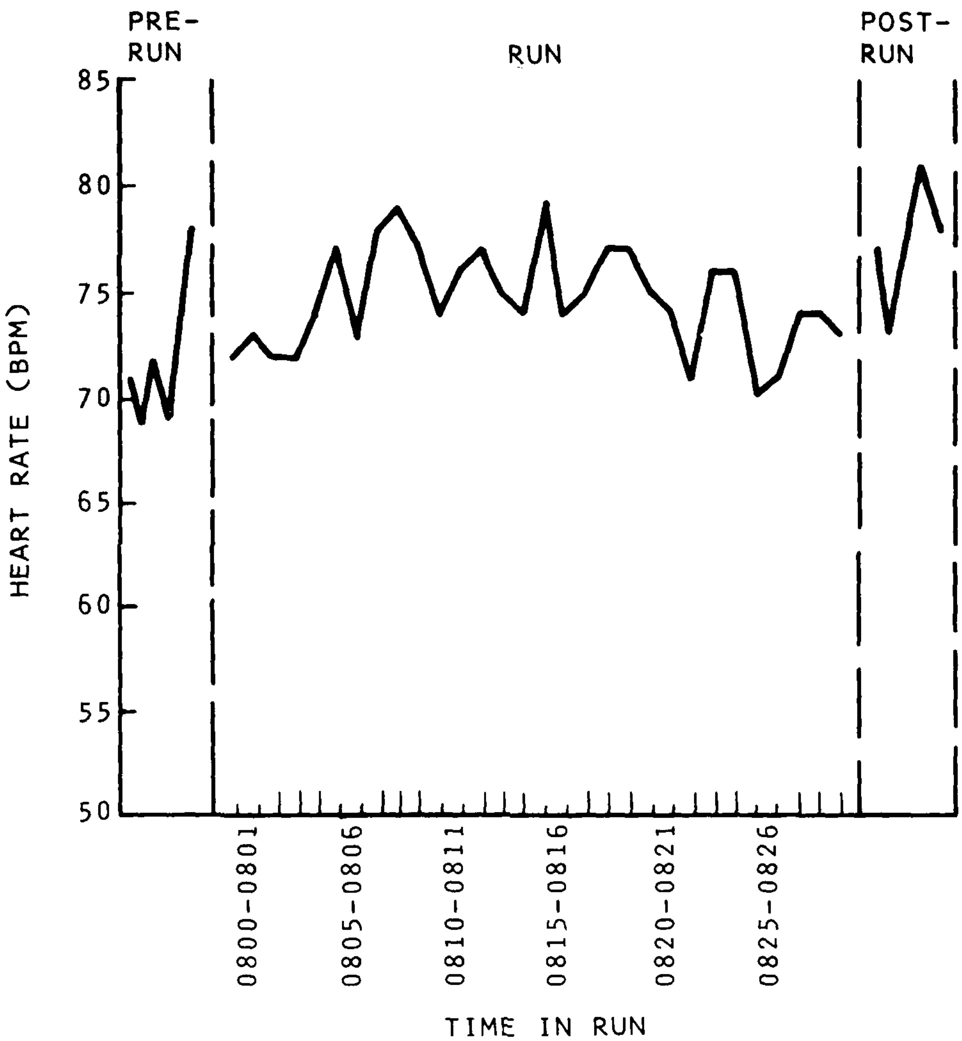

Figure 3-4. Subject 1's Heart Rate During the Two-Ship Encounter of Scenario 1

Figure 3-5 depicts Subject 1's progress through an encounter with four target vessels. In Figure 3-6, a more variable pattern of heart rate is evident for this run than in previous runs. In addition, a definite peak elevation of 83 beats per minute occurred at 10 minutes into the run. Figure 3-5 indicates that a course change to deal with the encounter occurred at this point in the scenario.

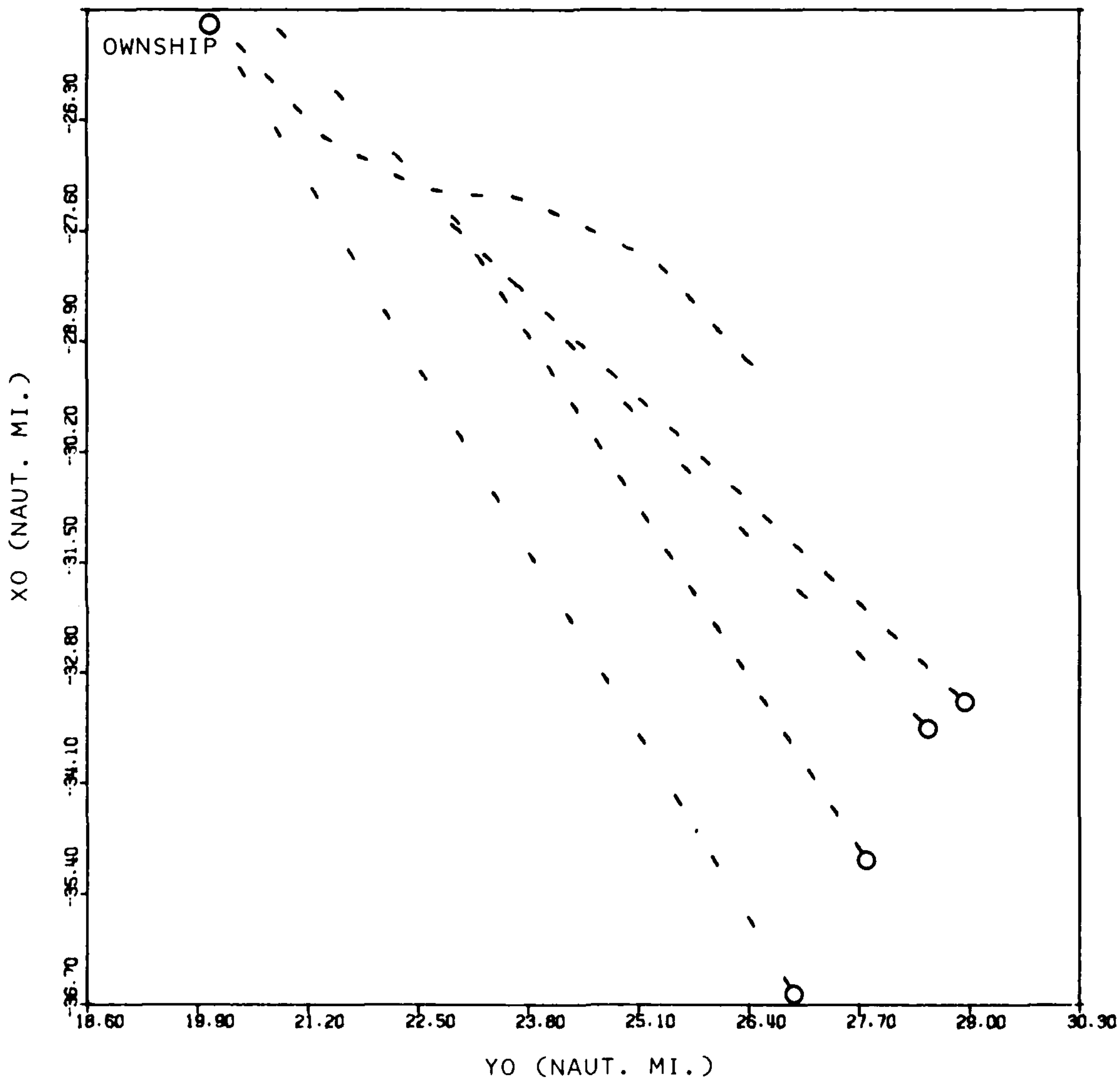

Figure 3-5. Subject 1's Course in the Four-Ship Encounter of Scenario 2

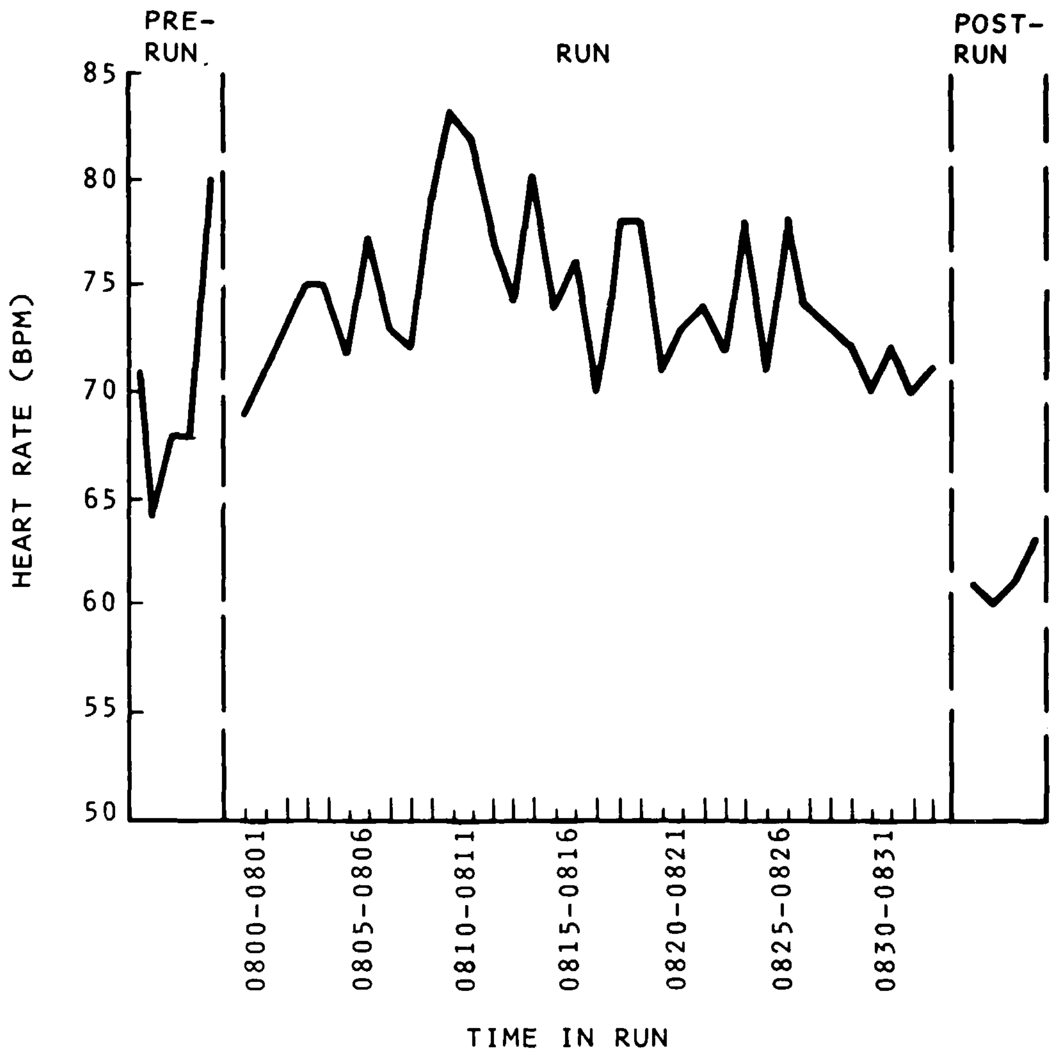

Figure 3-6. Subject 1's Heart Rate During the Four-Ship Encounter of Scenario 2

Figure 3-7 depicts the same subject's progress through the five-ship encounter, and Figure 3-8 presents the corresponding heart rate pattern. Three distinct periods of substantial heart rate elevation can be noted. Figure 3-7 indicates that these periods of elevation occurred concomitantly with course changes provoked by sequential encounters with target vessels. It can further be noted that a period of reduced heart rate followed the third elevation and continued through the end of the scenario and further decreased after the end of the run.

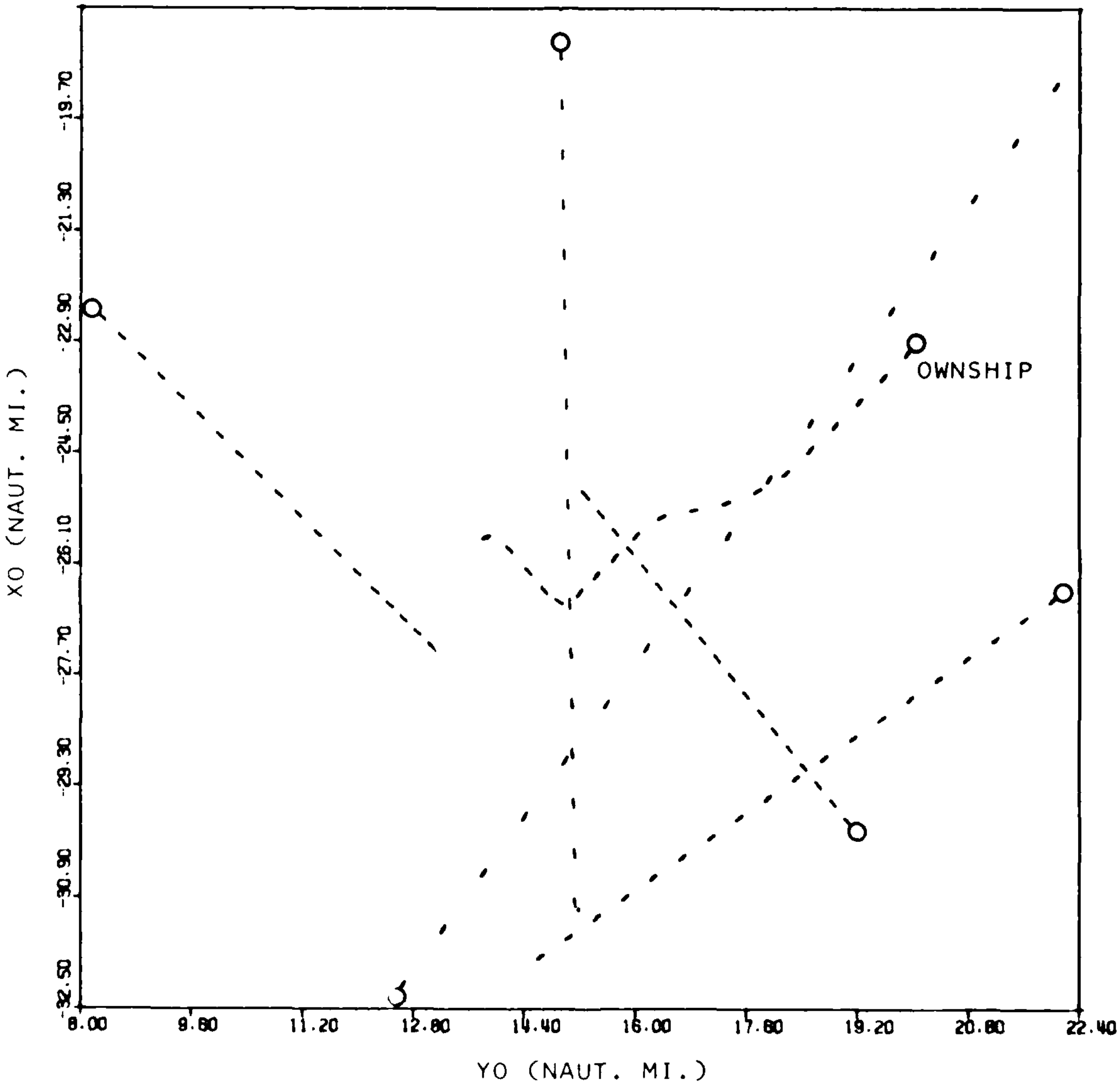

Figure 3-7. Subject 1's Course in the Five-Ship Encounter of Scenario 3

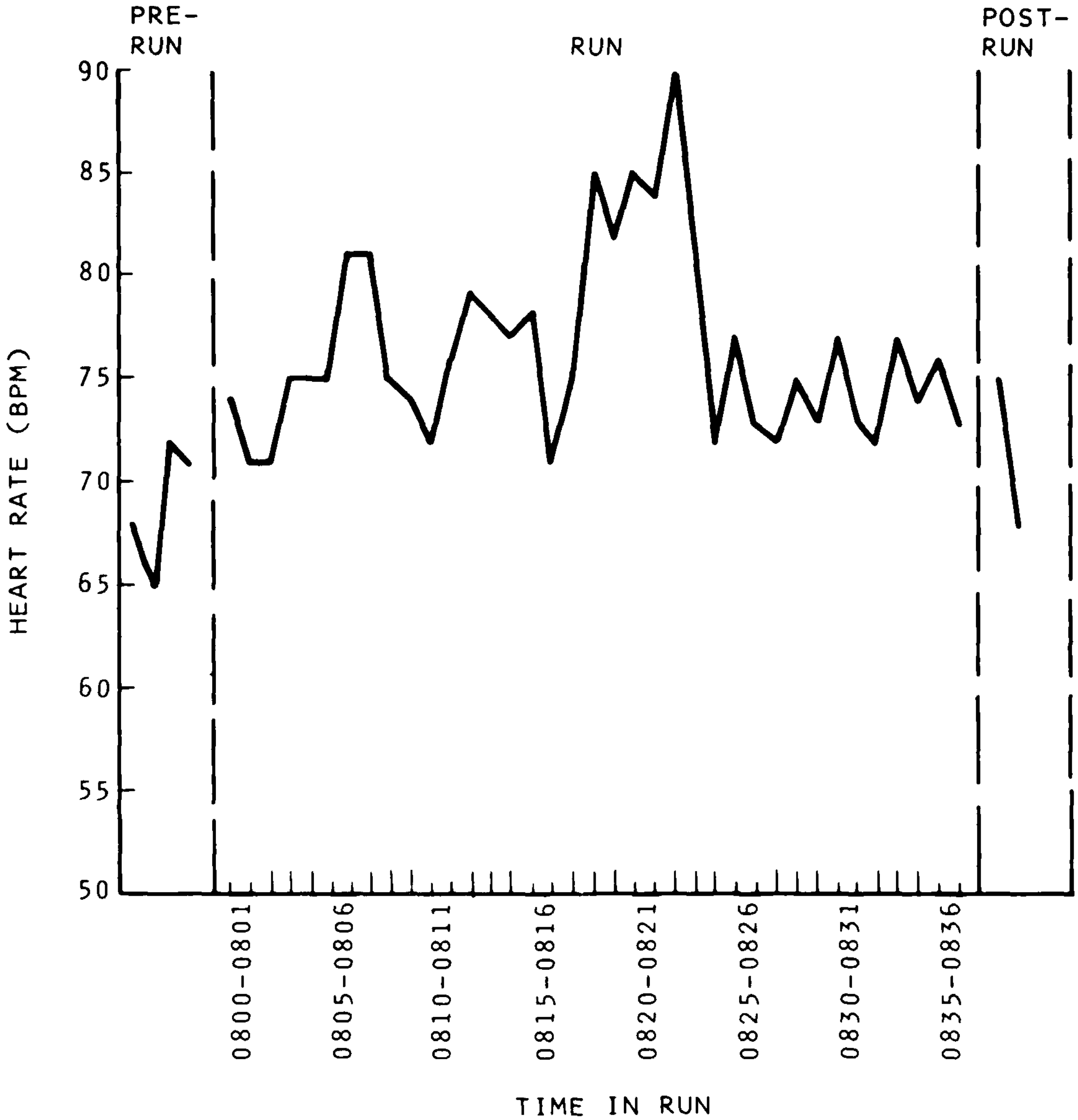

Figure 3-8. Subject 1's Heart Rate During the Five-Ship Encounter of Scenario 3

Several inferences may be drawn from the data generated in the open sea collision avoidance tasks.

1. These data indicate that collision avoidance encounters modeled on the simulator elicit physiological reactions indicative of emotional arousal in the mariner. This result affirms the validity of the CAORF simulator in reproducing credible real-world maritime conditions.

2. A comparison of physiological reactivity of the subject across the collision avoidance encounters for two, four, and five target ships, respectfully, suggests that the subject's level of reactivity is directly proportional to the complexity and navigational demands of the encounter. This suggests the "navigational complexity of a scenario can be evaluated and validated by monitoring the mariner's physiological reactions.

3. The periods of elevated heart rate manifested by the subject correlate well with decisuve points in the scenario. This is best illustrated in Figures 3-7 and 3-8 depicting the subject's heart rate and ownship's progress through the five target ship encounter. Heart rate elevations can be seen to have occurred in advance of a course change initiated to deal with a potential collision situation. Heart rate then decreased following a successful maneuver. This suggests that variations in heart rate in this particular subject mirrored well his involvement with the navigation problem, affirming the value of phsiological monitoring of heart rate in discerning instances of emotional arousal in maritime situations.

   It should be noted that the elevation in heart rate observed prior to the initiation of maneuvers occurred in the absence of significant increases in the subject's physical activity (e.g., pacing, walking back and forth between the radar unit and the chart table). During these periods, the subjects tended to remain stationary in front of the radar. Thus, the increased heart rate is not attributable to concomitant increases in physical workload.

3.3 RESULTS FROM COLLISION AVOIDANCE IN RESTRICTED WATERS SCENARIOS

Two subjects, referred to as Subjects 3 and 4, participated in this phase of the study. Subject 3 used a conventional radar system to conn the vessel, whereas Subject 4 used a PAD-type collision avoidance system with a navigation option.

Subject 3's heart rate patterns in this phase of the study are presented in Figures 3-9, 3-11, 3-13, 3-15, 3-17, and 3-18. Figure 3-9 depicts heart rate manifested by the subject while navigating in limited visibility through restricted waters with a vessel following at constant speed, 1/2 mile behind ownship. Although heart rate is relatively high throughout the entire run, but within normal limits, there were no periods of distinct elevation. Subject 3's heart rate throughout this run can be seen to be consistent with his pre-run rates diagramed in Figures 3-11, 3-13, 3-15, 3-17, and 3-18 to the left of the dashed vertical line, which represents the start of the run.

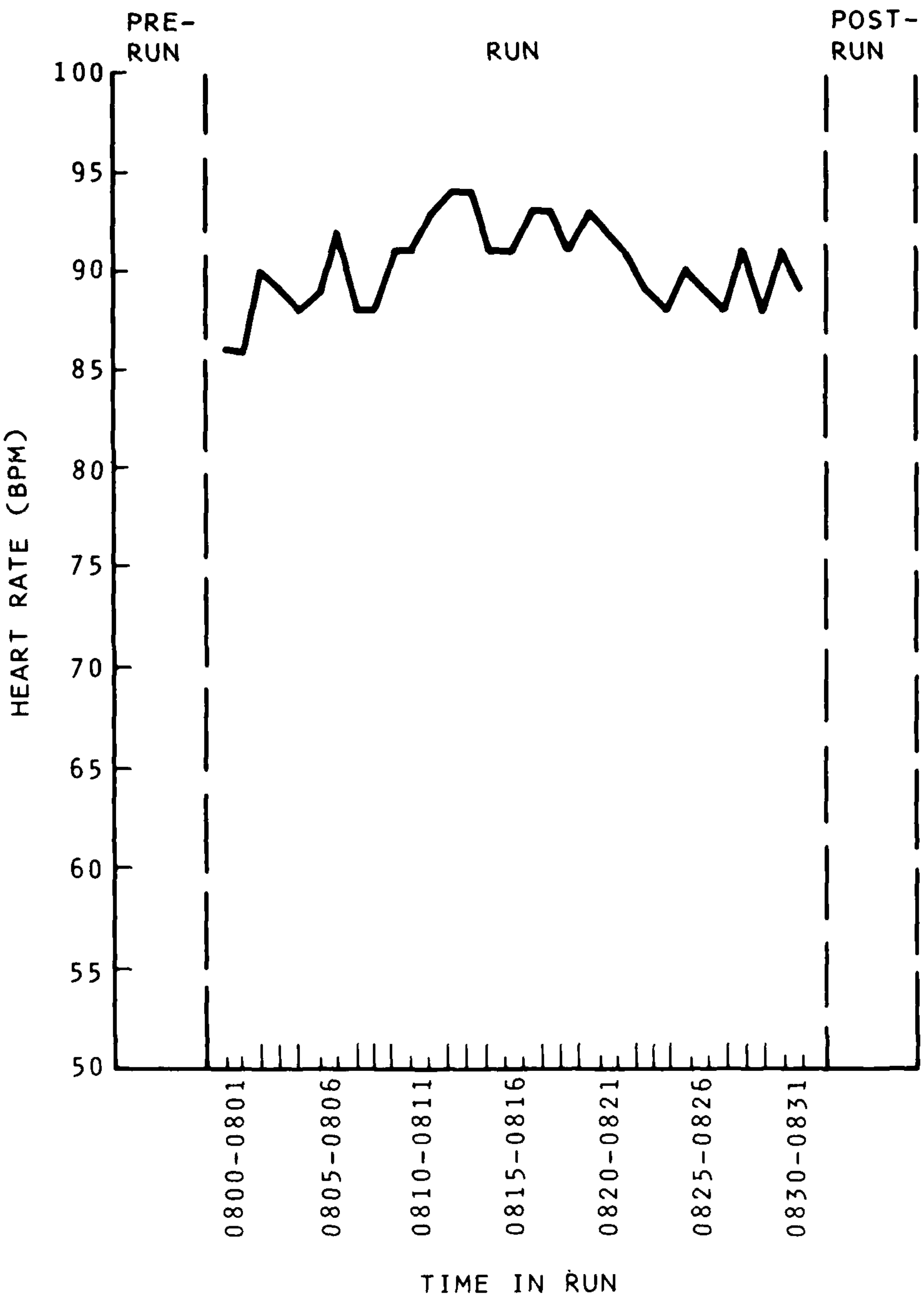

Figure 3-9. Subject 3's Heart Rate During a Preliminary Collision Avoidance Run

Figure 3-10 depicts Subject 3's progress through Scenario 4 (see Figure 2-7), while Figure 3-11 depicts his corresponding heart rate pattern. Heart rate increased gradually during the first 25 minutes of the run and then sharply to a peak of 112 beats per minute at 35 minutes into the run. The rate then declined through the end of the run. Reference to the bridge watch record indicated that a command of "Dead Slow" was issued at 26 minutes 40 seconds into the scenario, the first evident action taken to avert a potential collision. Thus, in this instance, heart rate elevation occurred concomitantly with the subject's first definitive action. At 36 minutes 45 seconds into the scenario a "hard left" command was issued resulting in a CPA of 91 feet. From the point of CPA the subject's heart rate declined steadily to the end of the run.

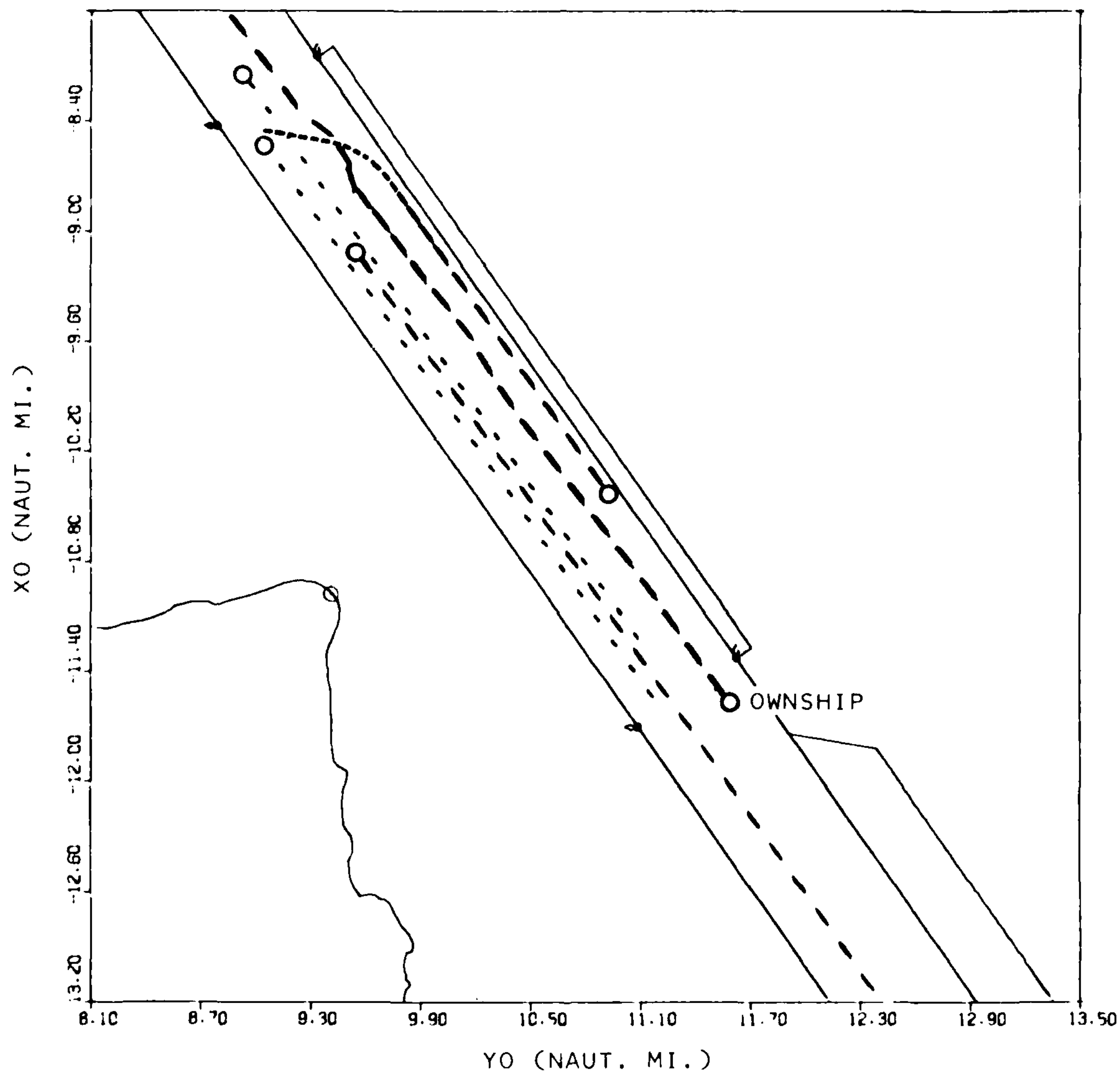

Figure 3-10. Subject 3's Progress Through Scenario 4

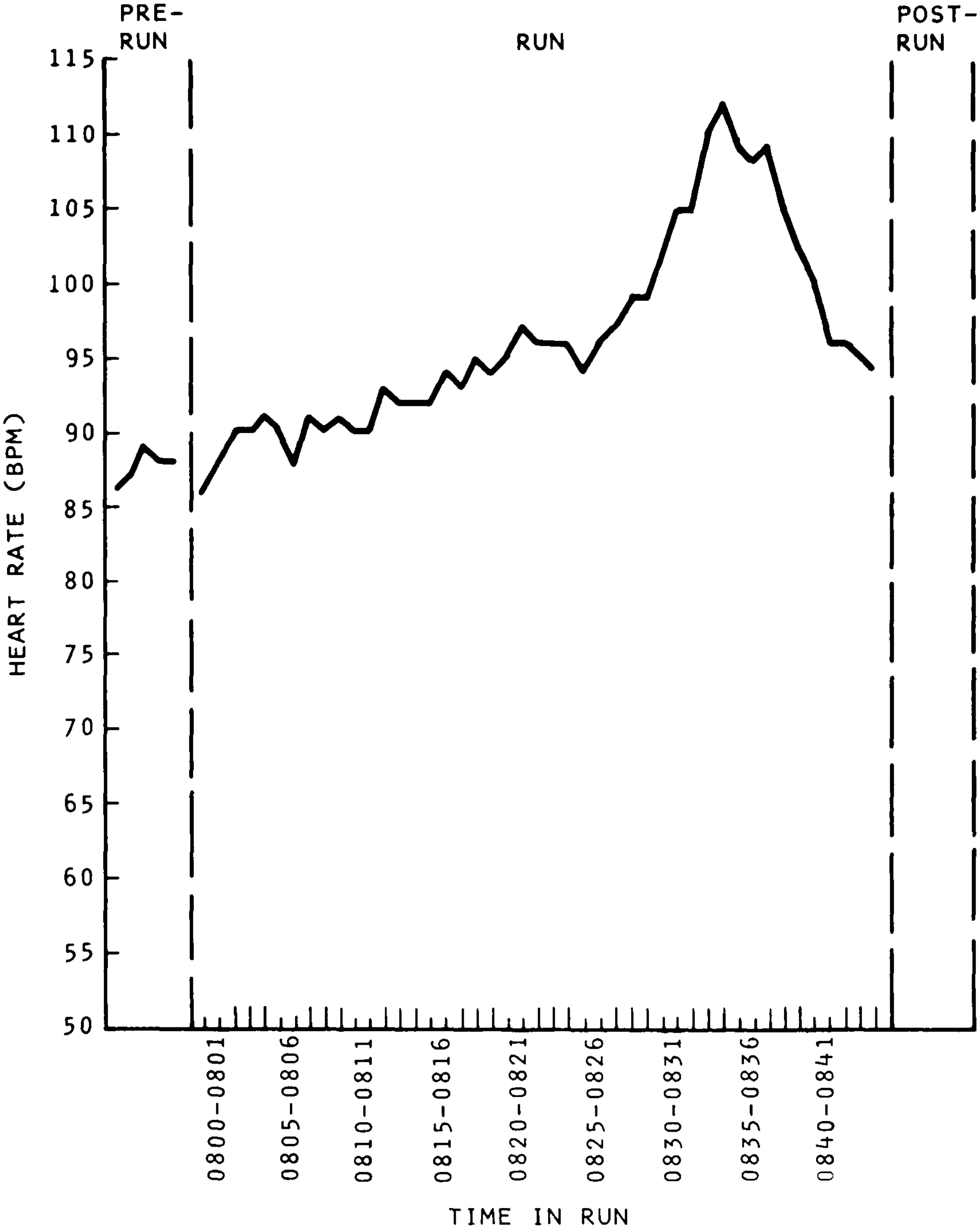

Figure 3-11. Subject 3's Heart Rate During Scenario 4

Figure 3-12 depicts Subject 3's progress through Scenario 5 (see Figure 2-8) while Figure 3-13 depicts his heart rate pattern through this run. As indicated in Figure 3-13, heart rate began to increase dramatically between 9 and 10 minutes into the scenario, remaining elevated until 21 minutes and then declining. The bridge watch record indicated that a command of "Dead Slow" occurred at 11 minutes 13 seconds into the scenario with a CPA of 558 feet occurring at 22 minutes 30 seconds. As in the previous run these key occurrences correspond perfectly with the subject's period of significant heart rate elevation.

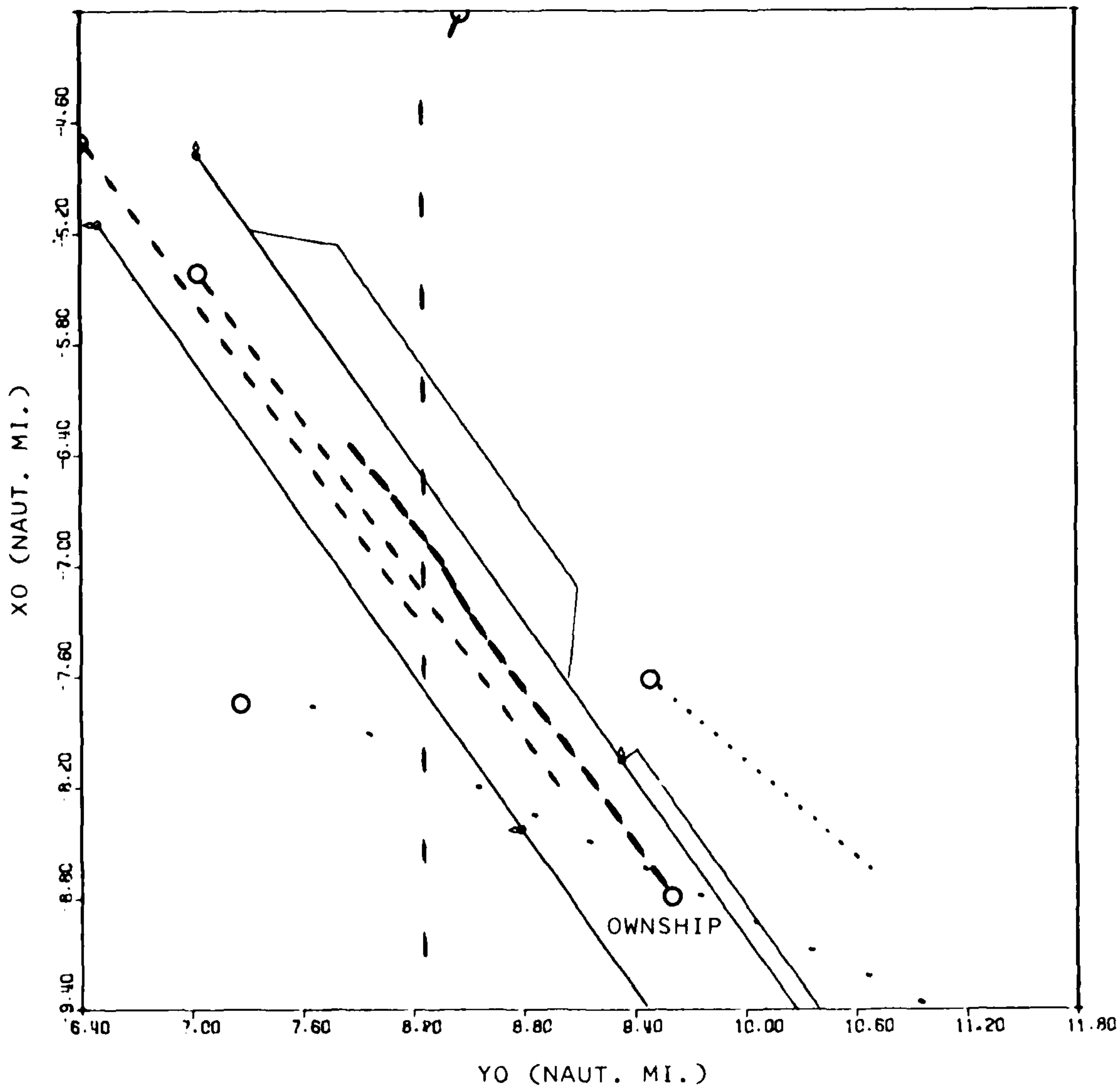

Figure 3-12. Subject 3's Progress Through Scenario 5

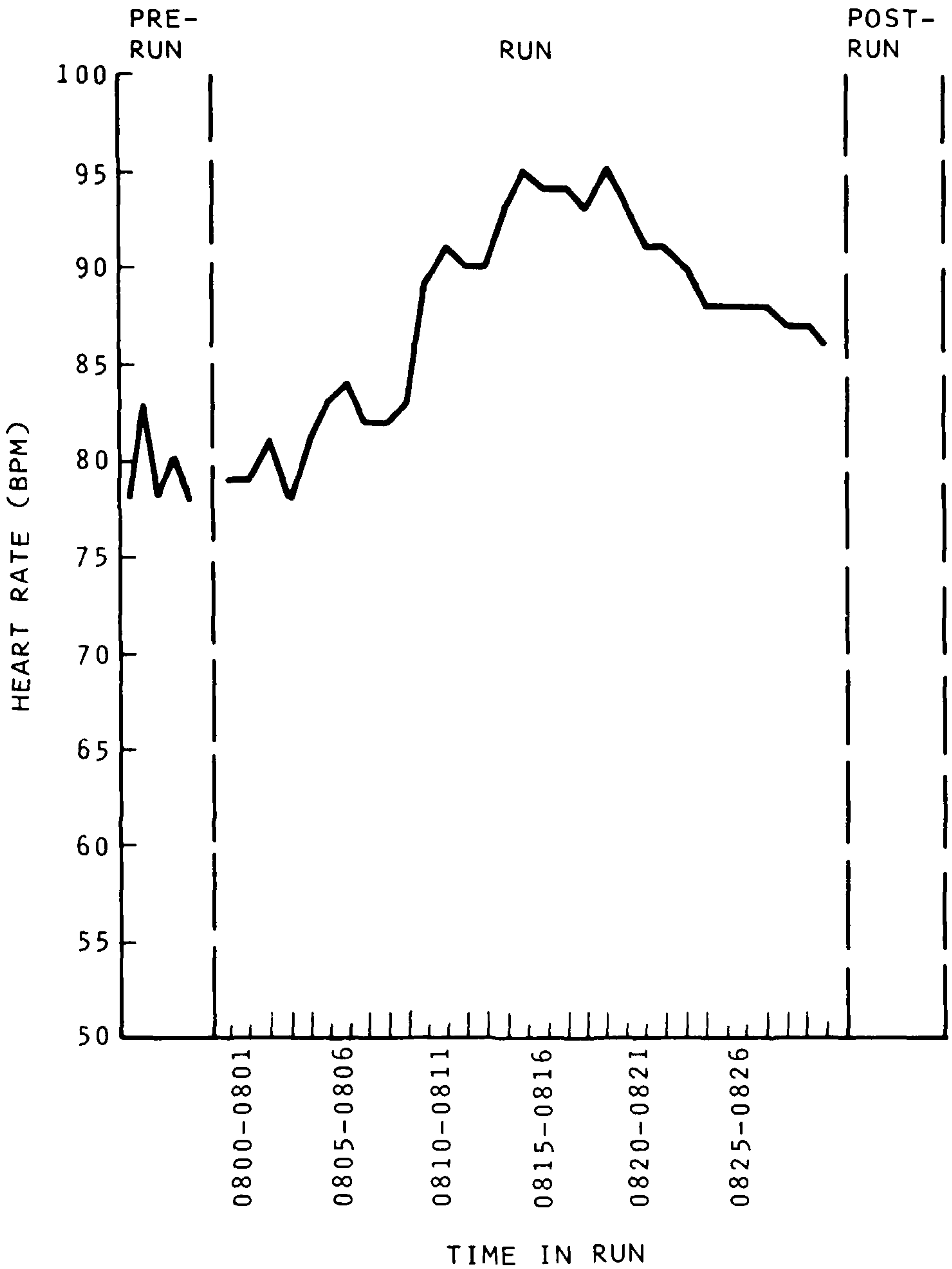

Figure 3-13. Subject 3's Heart Rate During Scenario 5

Figure 3-14 depicts Subject 3's progress through Scenario 6 (see Figure 2-9) while Figure 3-15 depicts his heart rate pattern through this run. The bridge watch record indicated that the command "Full Ahead" was issued at 22 minutes 30 seconds into the run in an attempt to avoid a rapidly approaching vessel. The record further indicated that a collision occurred with this vessel at 24 minutes 21 seconds. Reference to Figure 3-15 indicates that Subject 3's heart rate rose dramatically from a rate of 98 beats per minute to a peak elevation of 123 beats per minute in the 2 minute period between the issuance of the command and the collision. It can further be noted that there were no indications, either in the subject's overt behavior, i.e. commands, comments to the mate, etc., or in his physiological reactivity, that he had sensed the threat of a potential collision prior to 22 minutes 30 seconds into the scenario. Figure 3-15 further indicates that following the collision the subject's heart rate

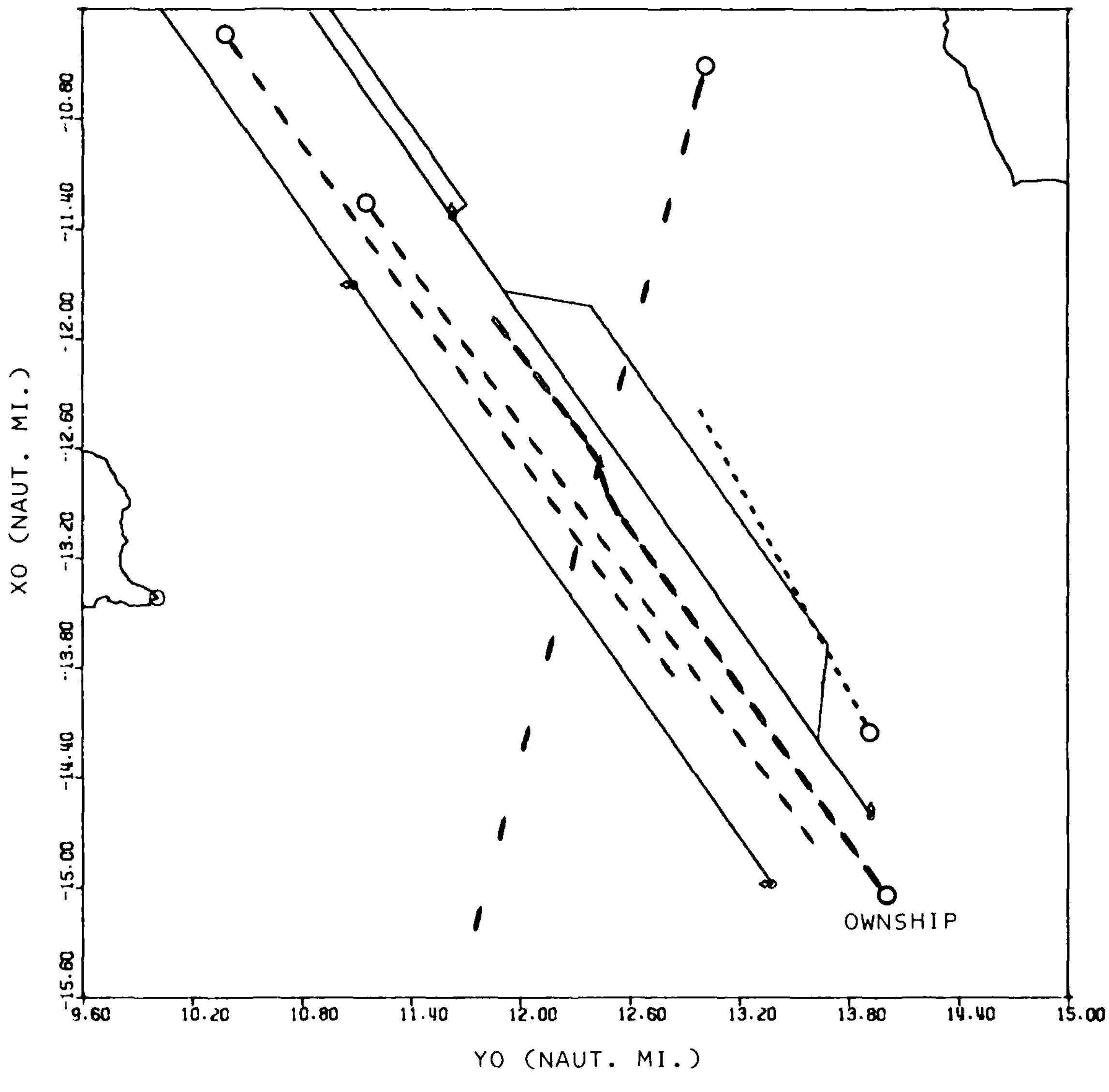

Figure 3-14. Subject 3's Progress Through Scenario 6

began to decline immediately, returning to pre-run levels within ten minutes after the collision occurred.

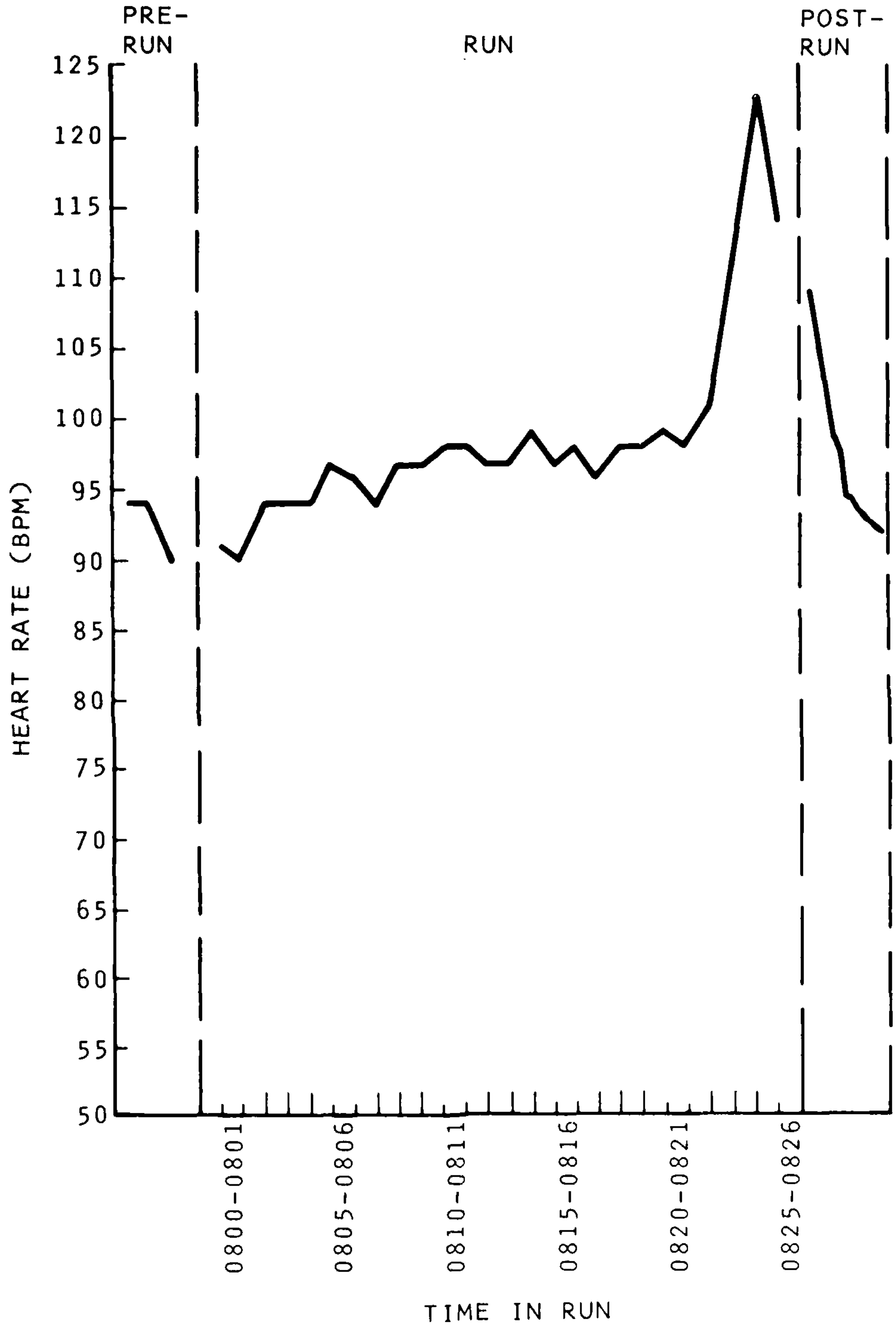

Figure 3-15. Subject 3's Heart Rate During Scenario 6

Figure 3-16 depicts Subject 3's progress through Scenario 7 (see Figure 2-10) and his heart rate pattern is presented in Figure 3-17. A steady increase in heart rate from the beginning of the run to a rate of 120 beats per minute at 24 minutes into the run can be noted. The command "Dead Slow" was issued at 16 minutes into the run and heart rate acceleration was particularly distinct from this point. A CPA of 309 feet was reached at 26 minutes. At this point in time the subject's heart rate began a steady decline to the end of the run.

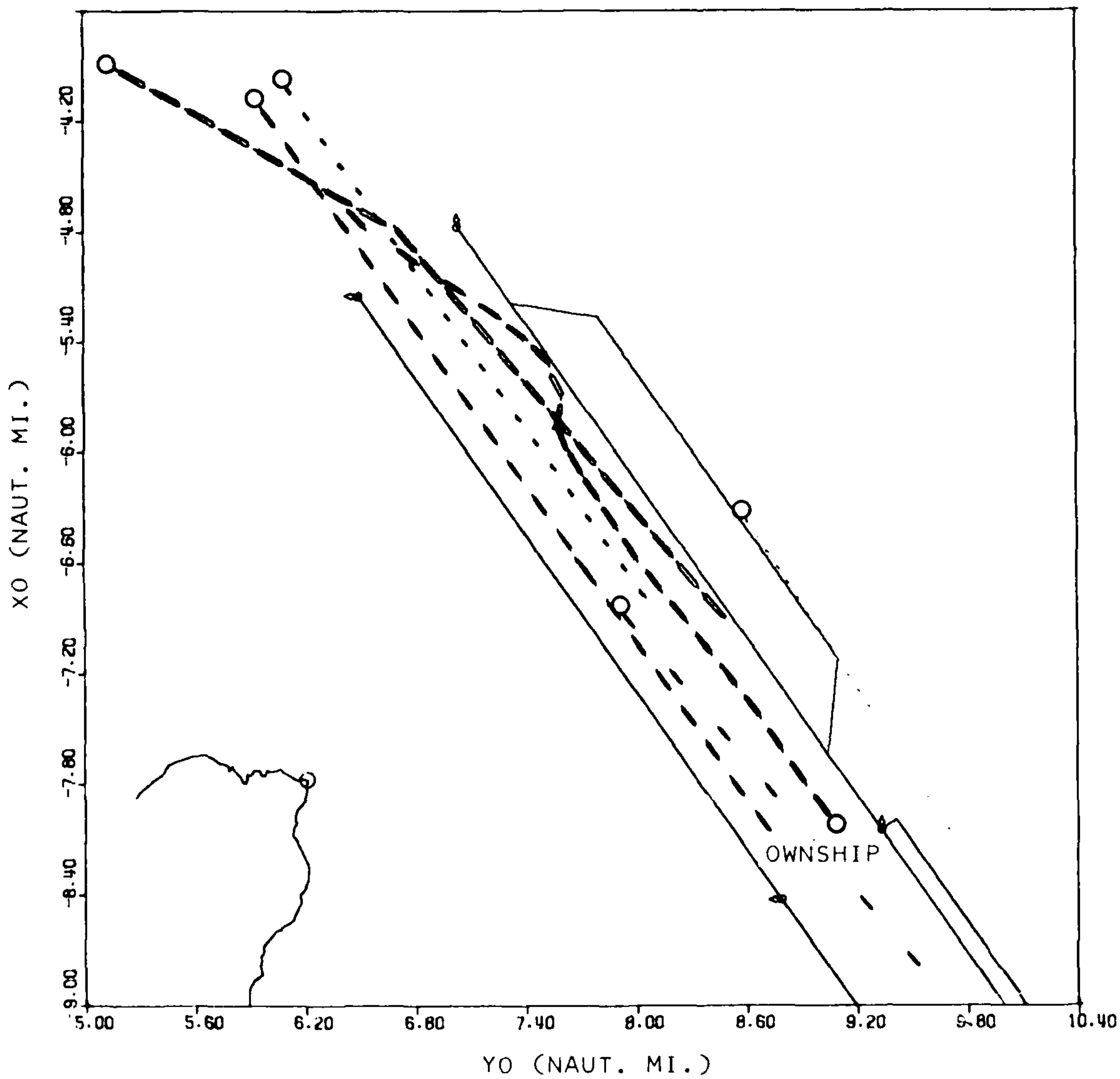

Figure 3-16. Subject 3's Progress Through Scenario 7

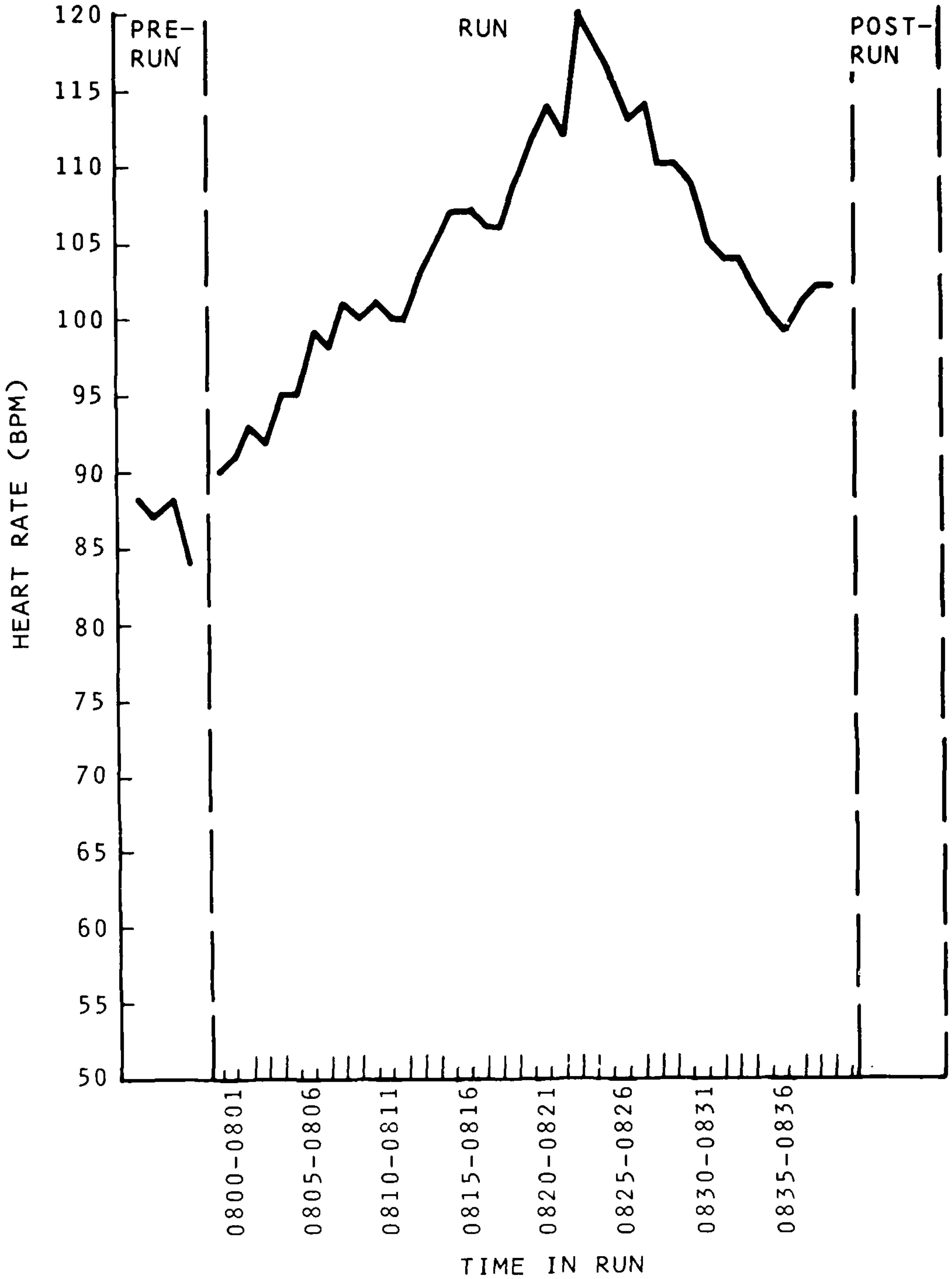

Figure 3-17. Subject 3's Heart Rate During Scenario 7

Subject 3's heart rate pattern during the open-sea collision avoidance scenario is presented in Figure 3-18. A plot of ownship's progress through this run was unobtainable but the scenario design is presented in Figure 2-6. It can be noted in Figure 3-18 that a sharp acceleration in heart rate began at 8 minutes into the run with the elevated rate of about 117 beats per minute continuing until 27 minutes into the scenario at which point it began to return to lower levels. A record of commands issued indicated that the heart rate acceleration occurred in advance of any action directed at dealing with the ship encounters, and continued until all traffic was clear.

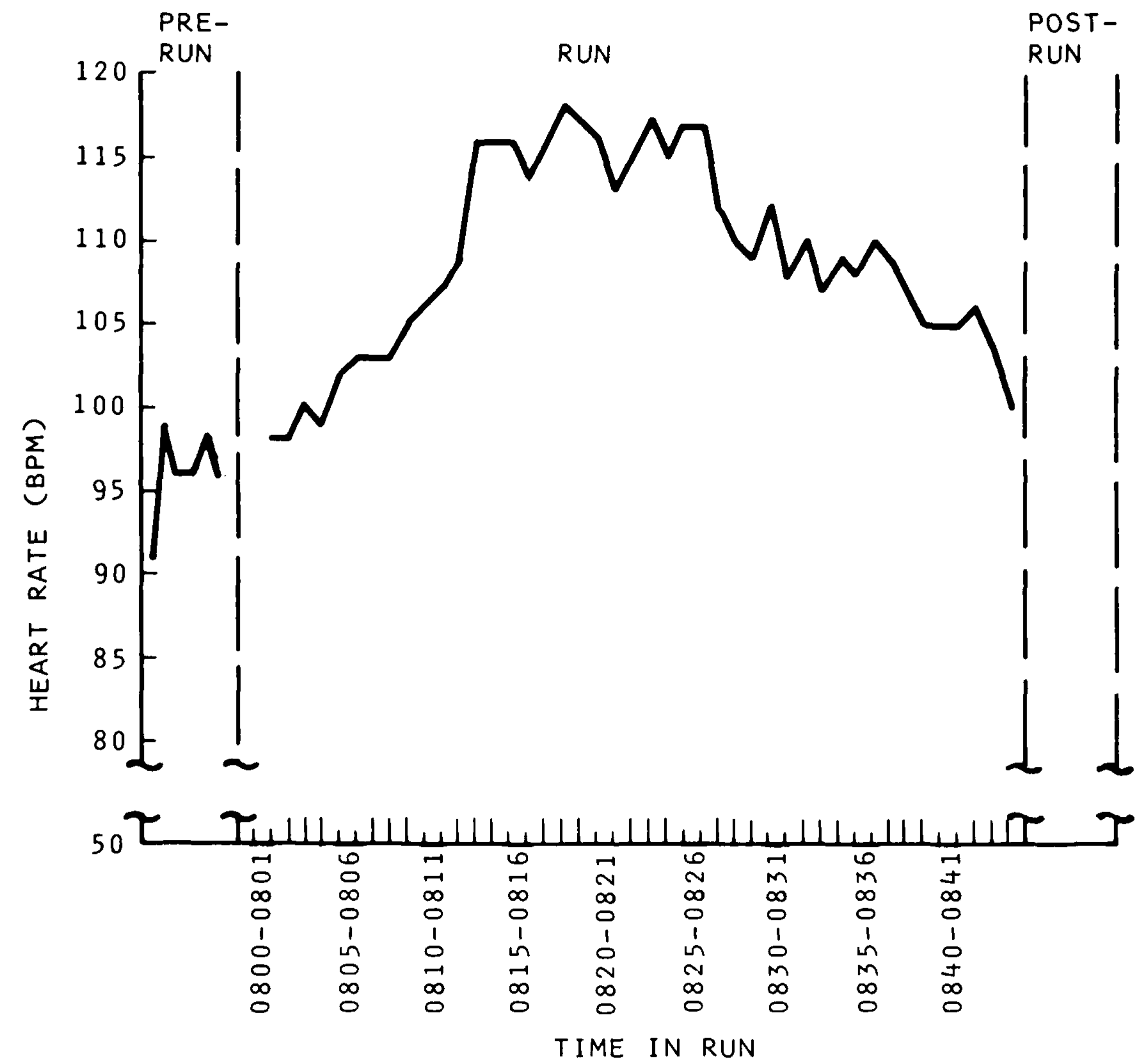

Figure 3-18. Subject 3's Heart Rate During the Open Sea Five-Ship Encounter of Scenario 3

Several points may be drawn from the Subject 3's data in this phase of the study:

1. The data of Subject 3, in this phase of the study, corroborate those of the subject in the first phase. It is evident that Subject 3 experienced periods of physiological reactivity that are clearly correlated with stressful and threatening situations. These periods are clearly correlated with critical points in the traffic ship encounters.

2. Physiological reactions of the subject did not occur until there was a clear behavioral indication that he was aware of the impending threat of the traffic vessels.

   These data give us some preliminary insight into the question of when a mariner becomes sensitive to a potential threat in a collision avoidance problem. The heart rate patterns of Subject 3 indicate that physiological reactions to the encounter occur concomitantly with action to avert the collision. It may be inferred that the onset of physiological reaction marks the earliest point that the mariner perceives the traffic encounter as a collision threat. It may be that the subject was aware of the progress of the traffic vessel prior to his physiological reaction but did not perceive the "threat element" until the point characterized by the heart rate acceleration. It may in fact be that the body's reaction that accompanies threat perception serves as an impetus for a decisive command.

Subject 4's heart rate patterns in the Collision Avoidance-Restricted Waters phase of the study are presented in Figures 3-19, 3-21, 3-23, 3-25, 3-27, and 3-28, and his progress through the scenarios is depicted in Figures 3-20, 3-22, 3-24, and 3-26. Two points are immediately obvious upon investigation of these heart rate patterns. The heart rate levels are relatively low, averaging around 60 to 65 beats per minute. Furthermore, in all encounters, *with the exception of Scenario 4, the subject's heart rate levels remained relatively* low with no periods of distinct elevation.

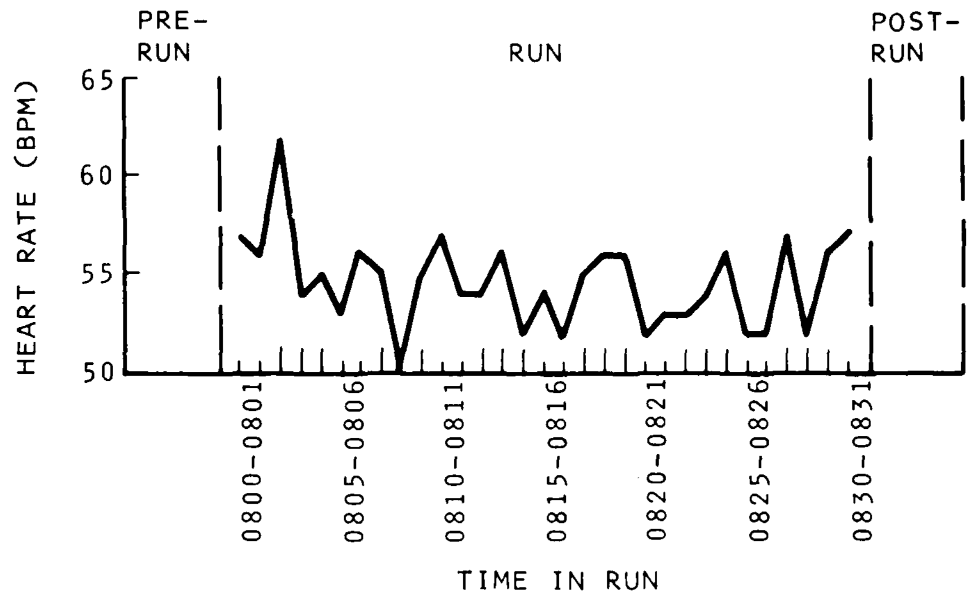

Figure 3-19. Subject 4's Heart Rate During a Preliminary Collision Avoidance Run

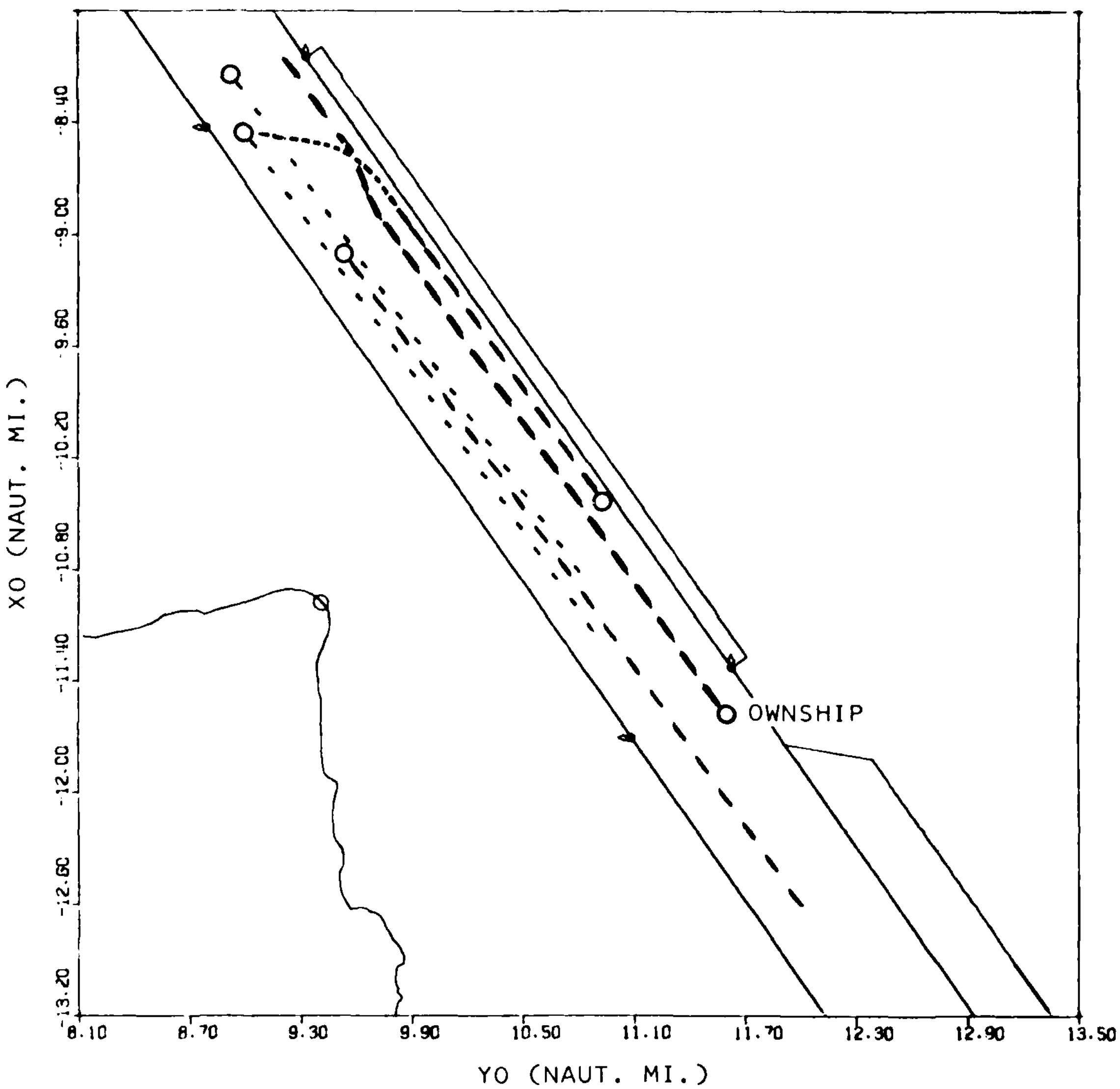

Figure 3-20. Subject 4's Progress Through Scenario 4

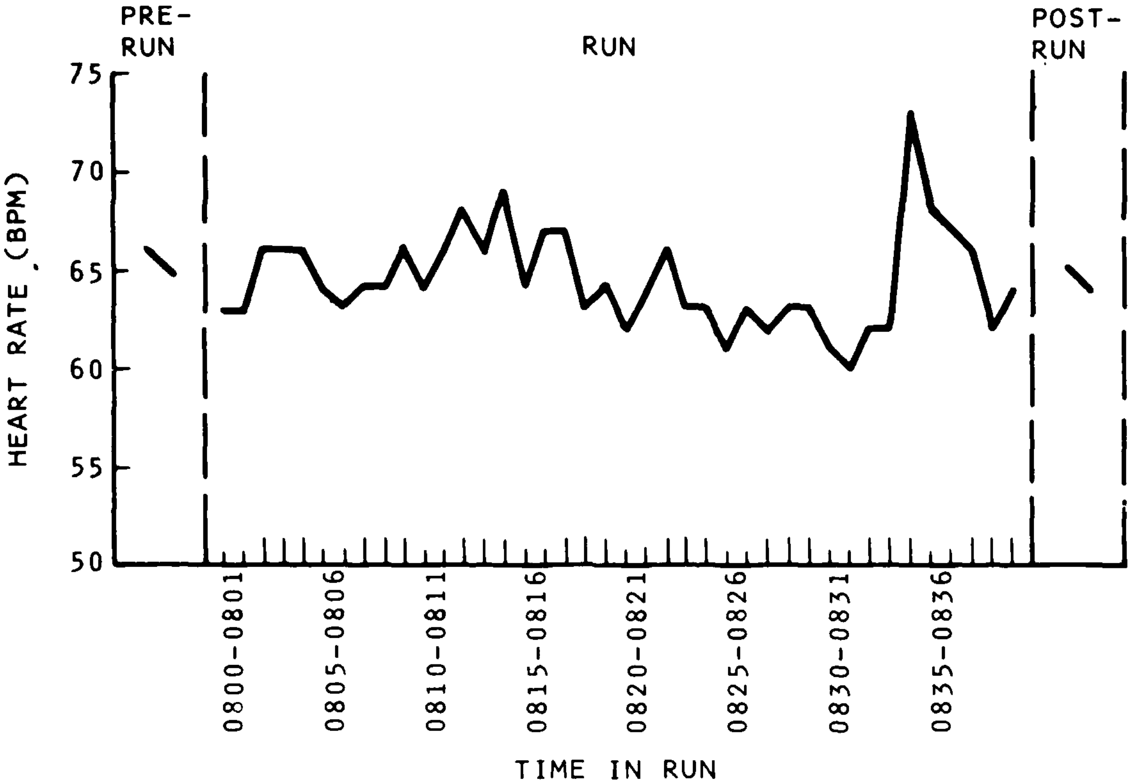

Figure 3-21. Subject 4's Heart Rate During Scenario 4

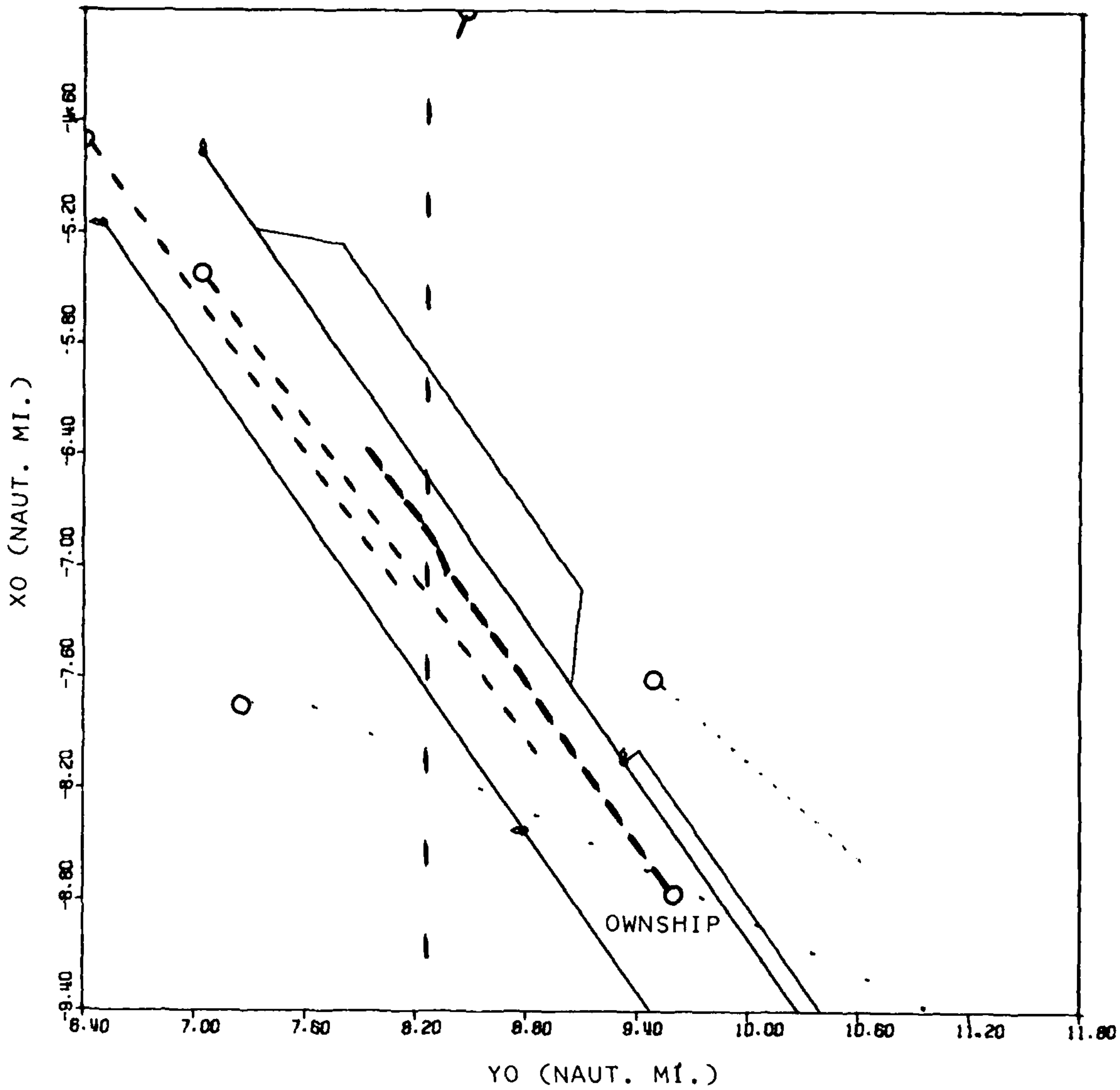

Figure 3-22. Subject 4's Progress Through Scenario 5

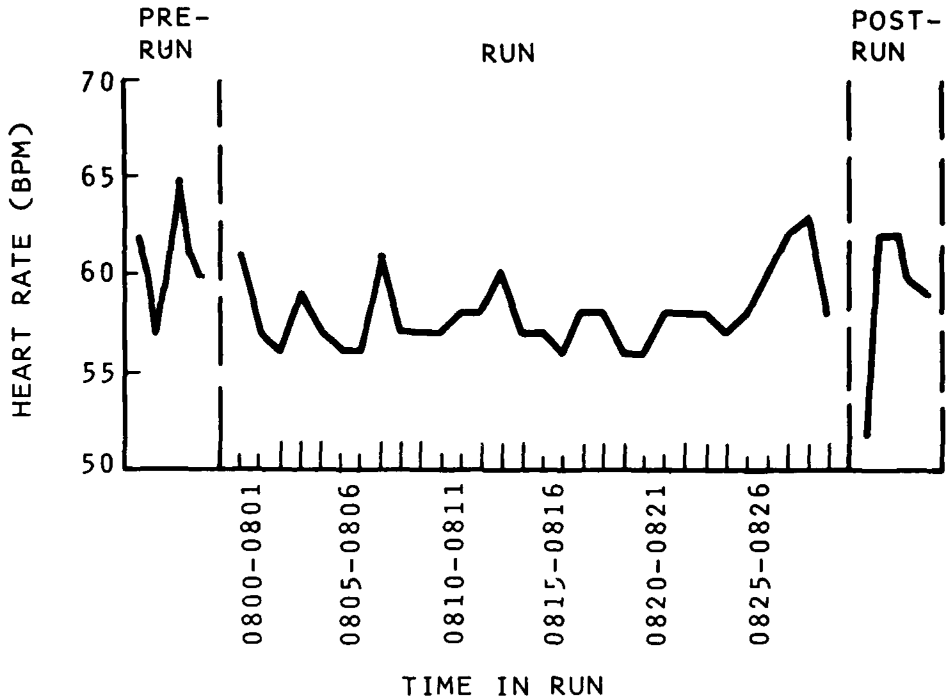

Figure 3-23. Subject 4's Heart Rate During Scenario 5

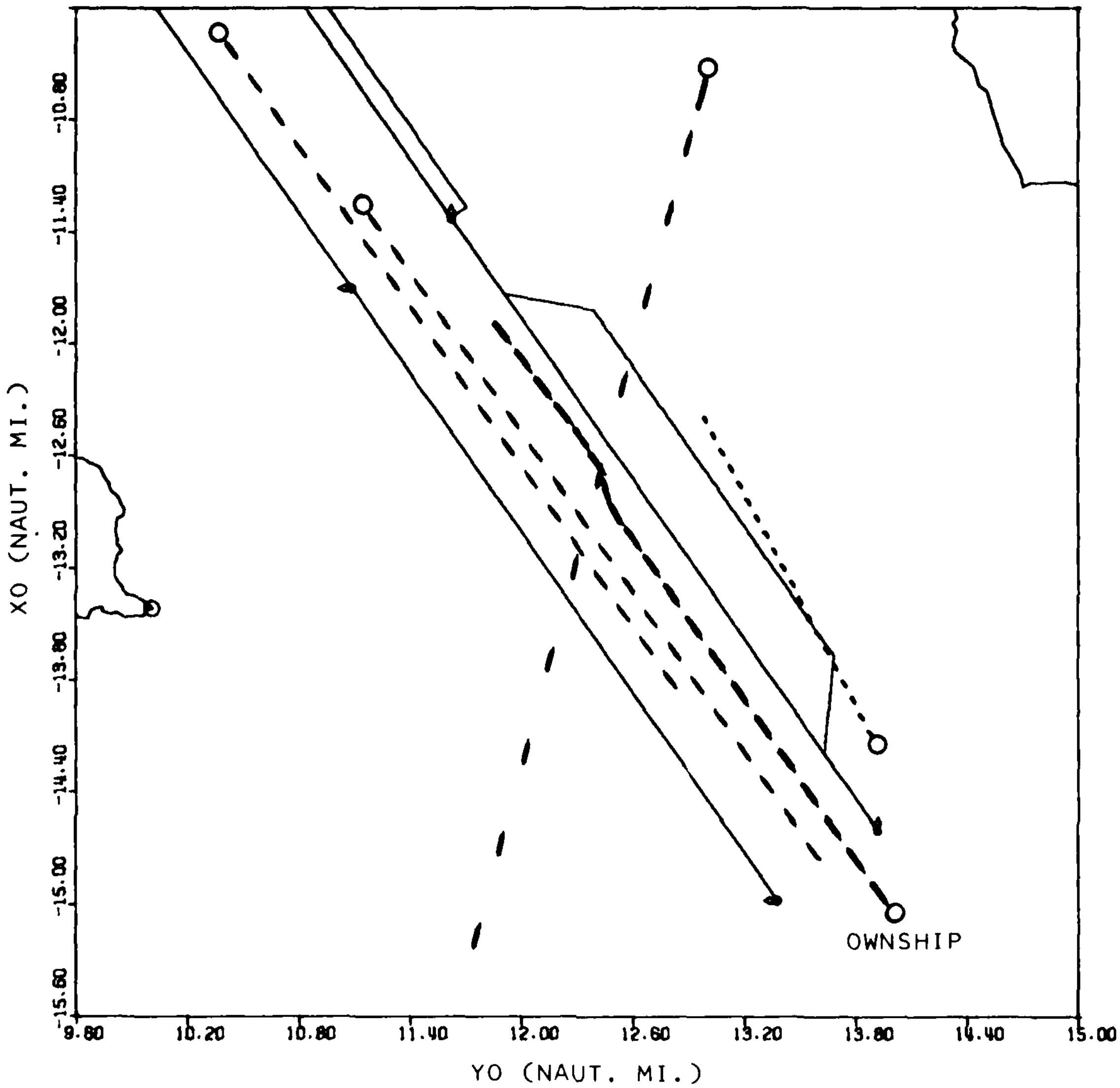

Figure 3-24. Subject 4's Progress Through Scenario 6

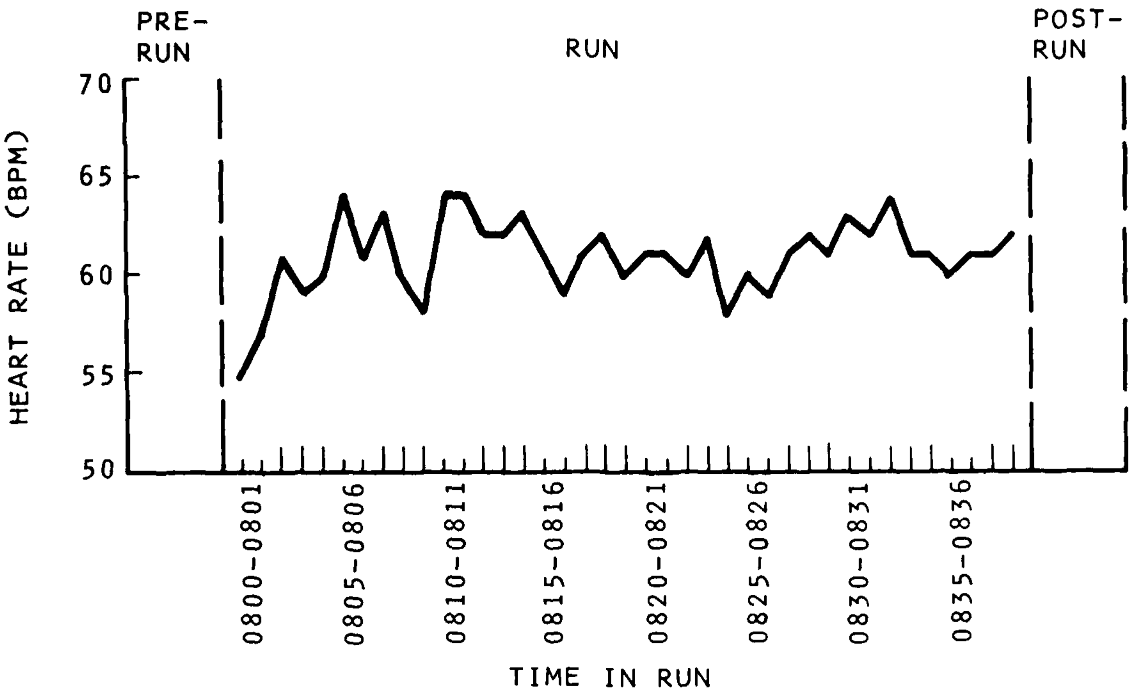

Figure 3-25. Subject 4's Heart Rate During Scenario 6

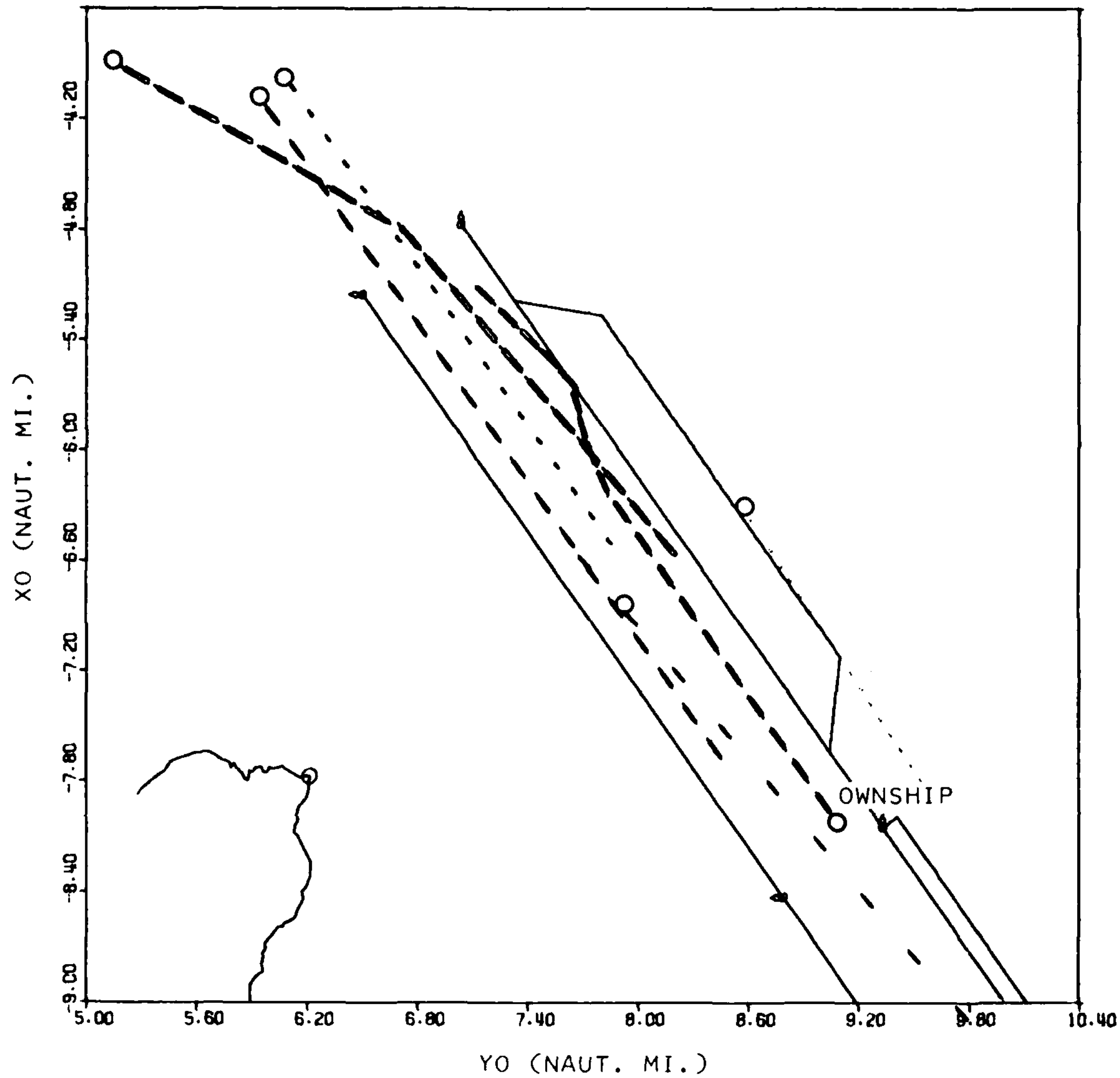

Figure 3-26. Subject 4's Progress Through Scenario 7

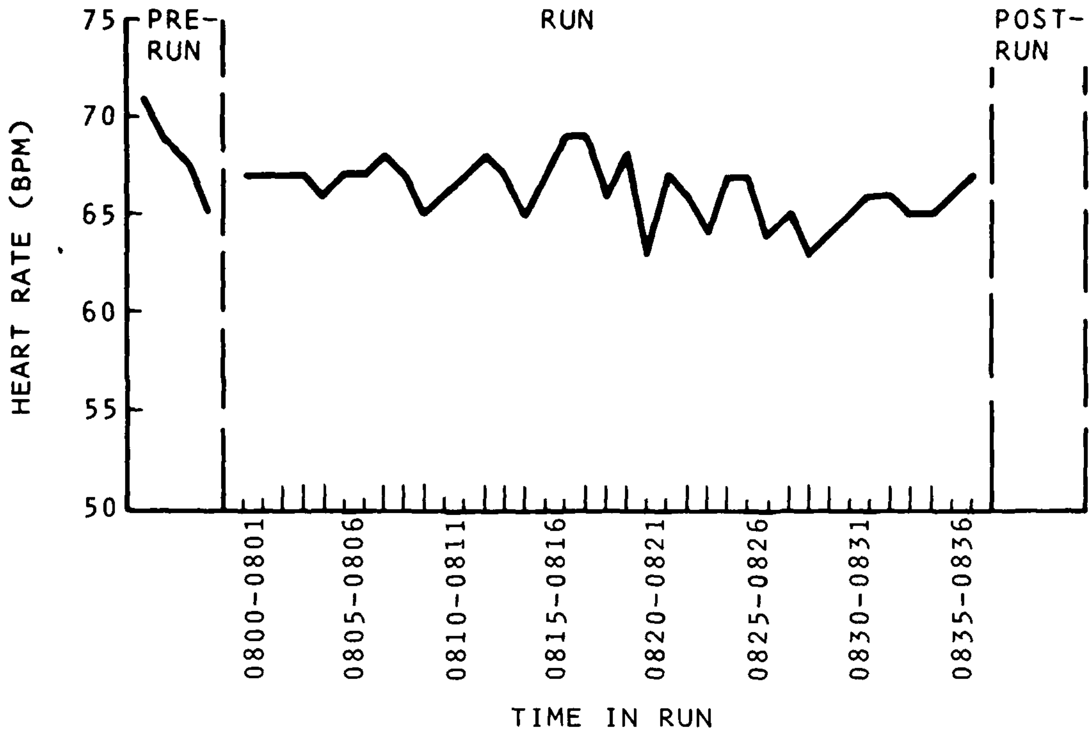

Figure 3-27. Subject 4's Heart Rate During Scenario 7

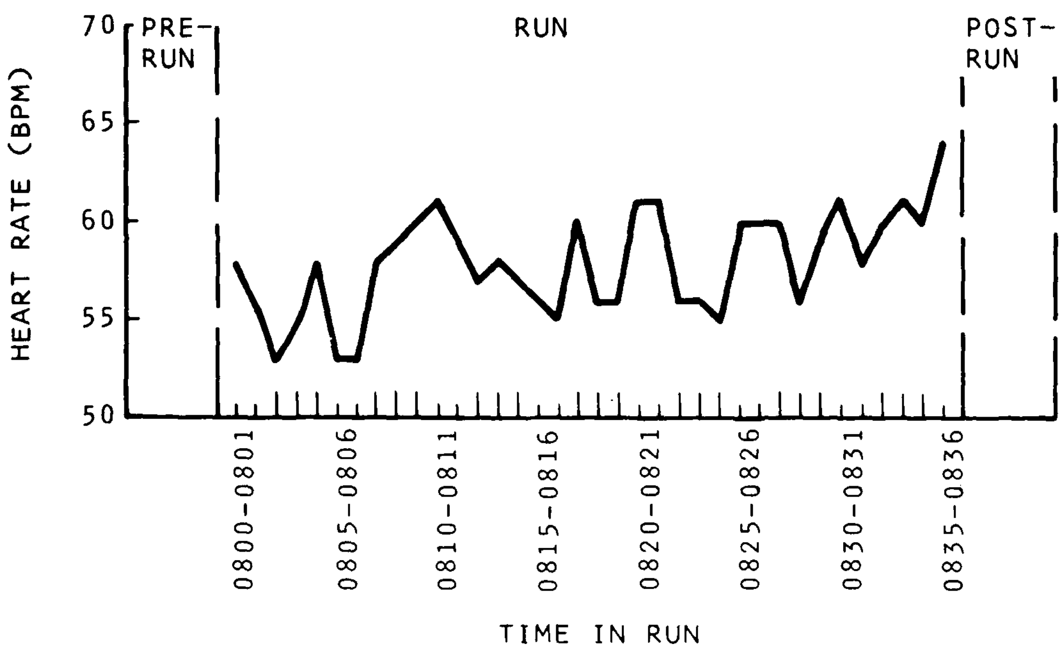

Figure 3-28. Subject 4's Heart Rate During the Open Sea Five-Ship Encounter of Scenario 3

A summary of Subject 3's performance data is provided in Table 3-1 and a similar compilation is presented for Subject 4 in Table 3-2. Subject 4's performance data indicate that these were specific points of decision in each scenario that may be deemed definitive in dealing with the target vessel encounters. However the subject's heart rate patterns during the scenarios indicate that there were no concomitant periods of heart rate elevation. The elevation that is notable in Scenario 4 occurred well after all traffic encounters had passed and thus cannot be attributed to navigation demands. It may be due to a momentary physical reaction of the subject but it is impossible to specify the exact cause.

TABLE 3-1 SUMMARY OF SUBJECT 3 PERFORMANCE DATA IN COLLISION AVOIDANCE – RESTRICTED WATERS

Scenario	Time in Run*			CPA (ft)
	1st Detection	1st Assessment	Collision Alert	
4	0805	0818:00	0826:40	91
5	0805	0810:40	0811:13	558
6	0805	0819:00	0822:30	0 (Collision)
7	0805	0815:30	0816:00	309

*Each run was started at 0800.

TABLE 3-2 SUMMARY OF SUBJECT 4 PERFORMANCE DATA IN COLLISION AVOIDANCE – RESTRICTED WATERS

Scenario	Time in Run*			CPA (ft)
	1st Detection	1st Assessment	Collision Alert	
4	0805	0823:07	0824:07	255
5	0805	0811:30	0813:35	325
6	0805	0816:29	0817:14	364
7	0805	0816:30	0817:23	766

*Each run was started 0800.

It is appropriate to discuss the obvious physiological differences between the two subjects. The data indicate that Subject 4 was less physiologically reactive than Subject 3. The most probable explanation of this difference is that Subject 4 is a "jogger," routinely running 2 to 3 miles per day. Undoubtedly, this contributed to his overall low heart rate and might also contribute to his apparent lack of reactivity. Although this is the most probable explanation, one might draw an inference that the differences in these subjects are in part due to the different navigation devices they used. Recall that Subject 3 used a conventional radar system for navigation while Subject 4 used a PAD type CAS system with a navigation aid. The performance data, Tables 3-1 and 3-2, indicate that first maneuvers to avert collisions occurred at roughly comparable points in time for both subjects; however CPAs were larger overall for the CAS plus navigation option subject (Subject 4). This appears to indicate that maneuvers undertaken by Subject 4 may be considered "bolder" than those of Subject 3. This inference is in accord with a conclusion drawn in the Collision Avoidance-Restricted Waters study (Hayes, 1978) that CAS plus navigation option subjects tended to undertake "bolder" maneuvers than did radar subjects.

Thus one may tend to draw the inference that the CAS plus navigation option system, which provides a higher degree of proficiency to a navigator than does the conventional radar system, may account for a portion of the difference in physiological reactivity of these two subjects. It may be that the availability of a more informative navigation system reduces the physiological reactivity of a mariner. One cannot ignore, however, the data from Scenario 6; see Figures 3-18 and 3-28 for each subject's heart rate pattern, and Figure 2-6 for a depiction of the design of the scenario. Both subjects navigated this scenario with a conventional radar system. The data indicate that Subject 4 was less physiologically reactive than Subject 3. It is also possible that this difference in heart rate reactivity may reflect a difference in their proficiencies as mariners.

Data for Subjects 3 and 4 furthermore afford the opportunity to question whether the heart rate monitoring procedure employed in this study could itself have influenced the subjects' navigation performance. Comparison of the present subjects' performance (Tables 3-1 and 3-2) with that of previous subjects for whom no heart rate monitoring was carried out, indicates that the performance of Subjects 3 and 4 is consistent with and comparable to previous performance. This indicates that the heart rate monitoring procedures employed appear to have no discernible effect on the performance of a mariner at CAORF.

3.4 RESULTS FROM NEW YORK HARBOR SCENARIO

Two questions were addressed in this phase of the study. One concerned whether or not significant variations in heart rate are evident as mariners navigate through New York Harbor, and the second concerned whether or not sinus arrhythmia is applicable as a measure of the mental workload incurred while navigating.

Figure 2-11 depicts a typical course line through the New York Harbor scenario. Figures 3-29, 3-30, 3-31, and 3-32 represent the heart rate patterns of Subject 5 on four separate runs through this scenario. In figures 3-29 and 3-31, distinct periods of heart rate elevation can be seen toward the end of the runs. These elevations occurred while navigating through the area between the Bayonne Bridge and the Bayonne Draw. The elevation indicated in Figure 3-29 was concomitant with a close encounter with a tug. The elevation in Figure 3-31 occurred when the current produced a difficulty in aligning to maneuver through the Bayonne Draw. On the two other runs for this subject, no difficulties were encountered and no periods of heart rate elevation occurred.

Figures 3-33 and 3-34 represent similar New York Harbor runs for Subjects 6 and 7 respectively. Periods of moderate heart rate elevation can be noted for both subjects. As with Subject 5, these periods of elevation occurred rounding Bergen Point and approaching the Bayonne Bridge and Draw.

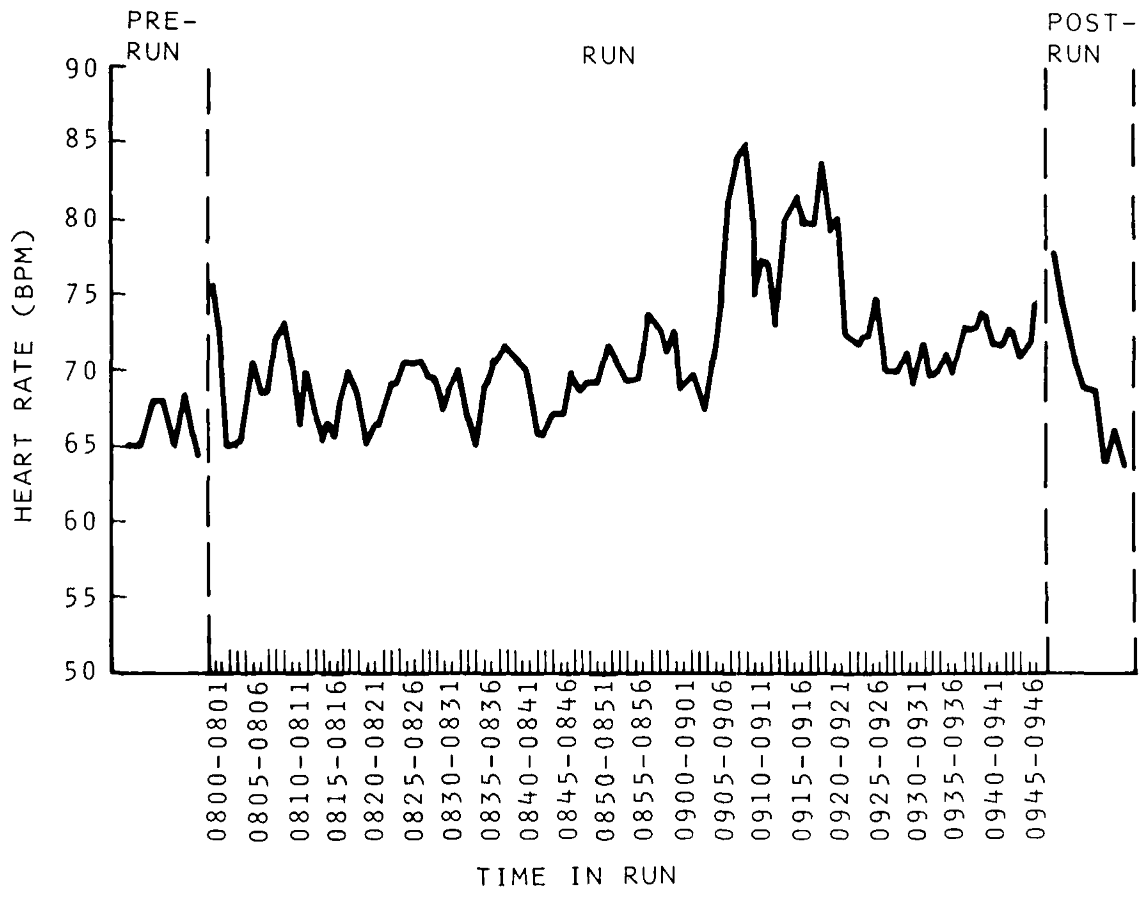

Figure 3-29. Subject 5's Heart Rate During First New York Harbor Run

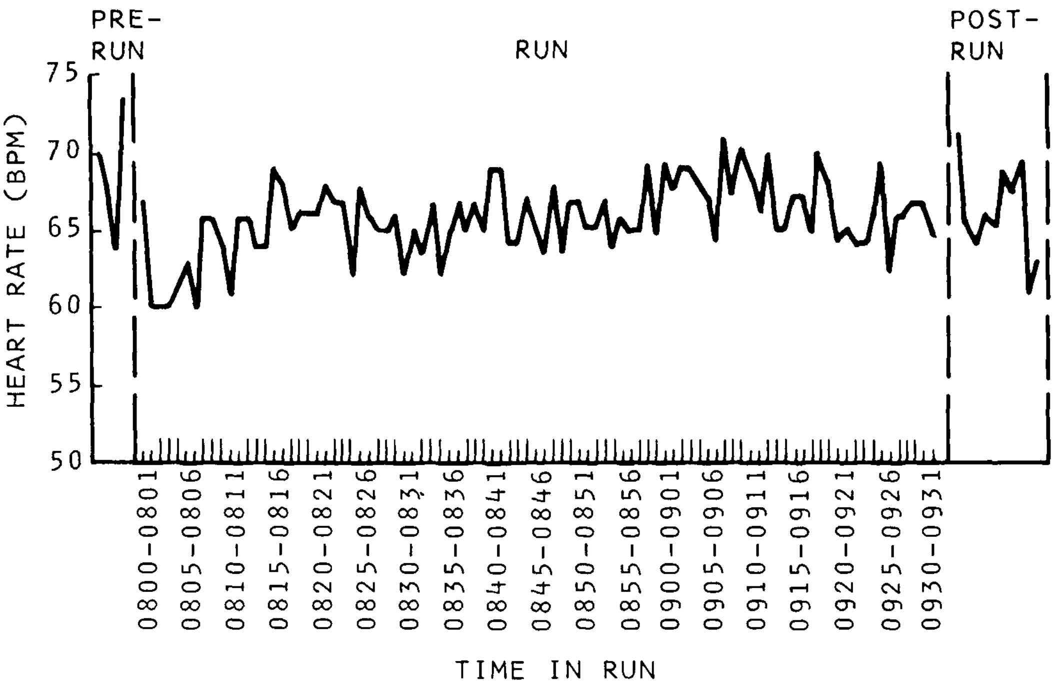

Figure 3-30. Subject 5's Heart Rate During Second New York Harbor Run

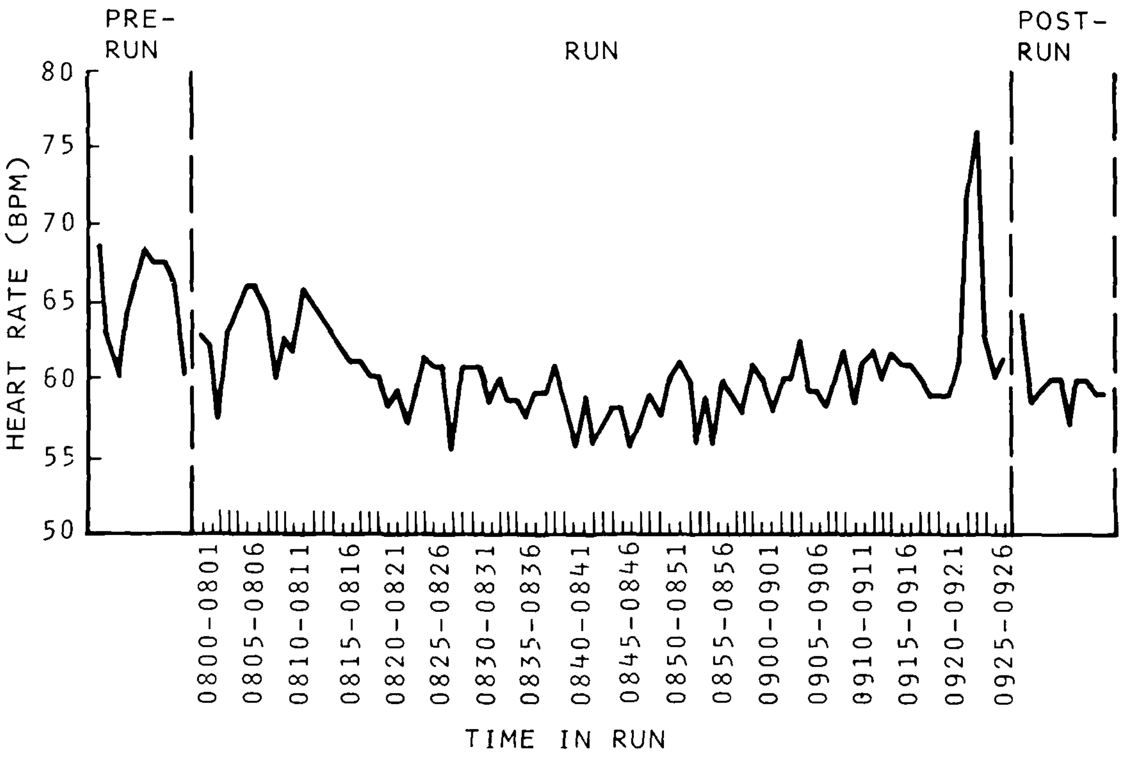

Figure 3-31. Subject 5's Heart Rate During Third New York Harbor Run

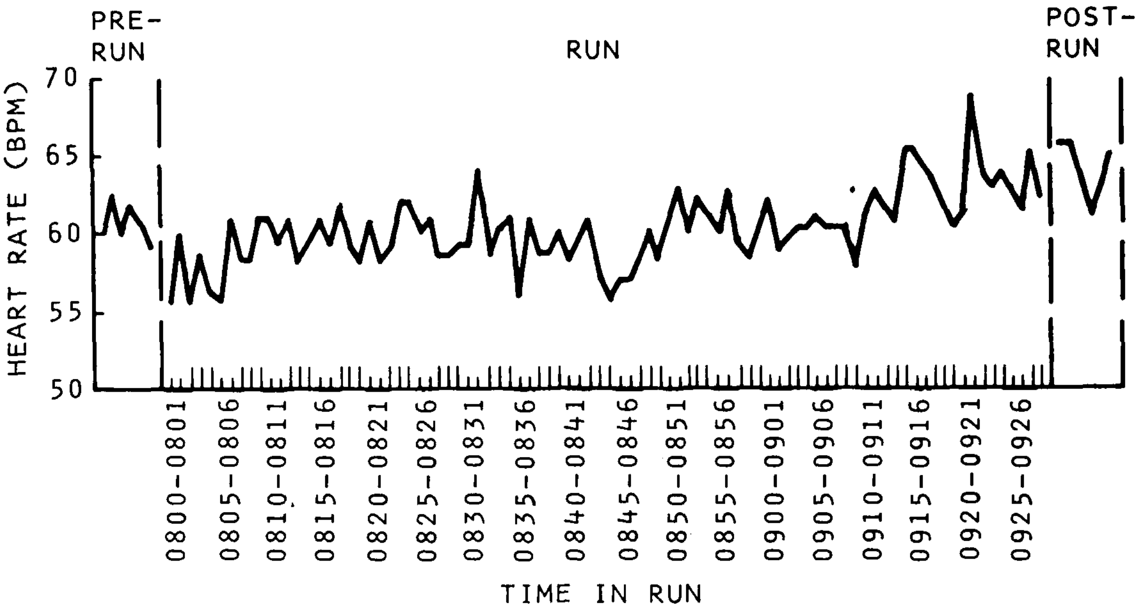

Figure 3-32. Subject 5's Heart Rate During Fourth New York Harbor Run

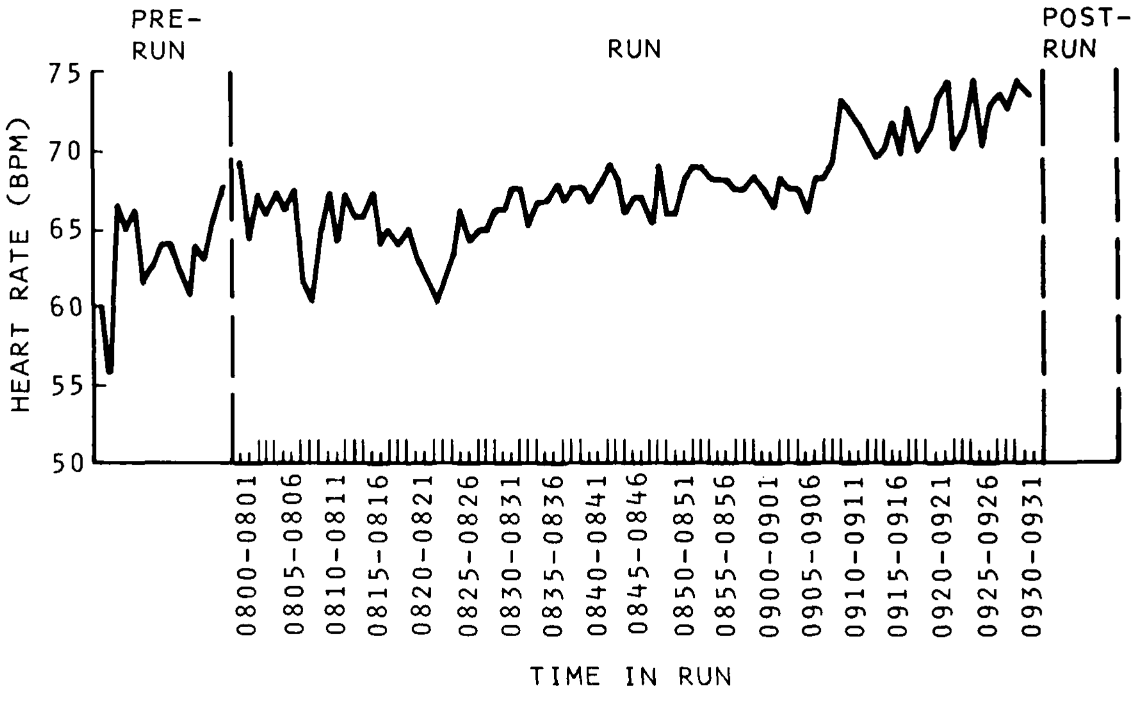

Figure 3-33. Subject 6's Heart Rate During New York Harbor Run

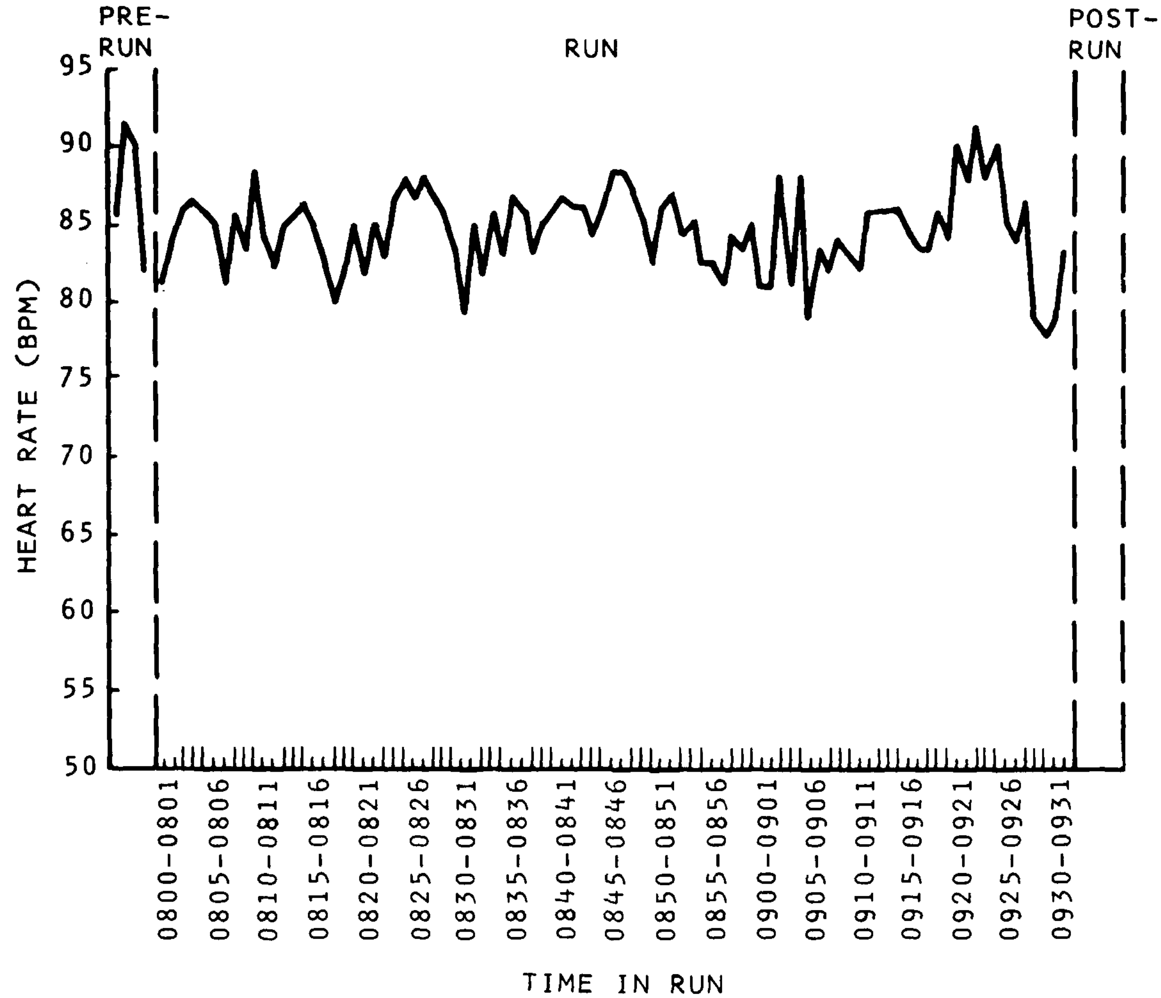

Figure 3-34. Subject 7's Heart Rate During New York Harbor Run

These data confirm informal reports of the New York-Sandy Hook pilots that the areas of Bergen Point and the Bayonne Bridge and Draw are the most demanding in this particular run. It further indicates that heart rate elevation is not limited to extremis conditions such as collision avoidance.

To assess the applicability of sinus arrhythmia as a measure of the mental workload accompanying a navigation task, data were collected on three additional subjects (8, 9, and 10).

The first subject experienced two New York Harbor VTS runs. One run was under unlimited visibility conditions with VTS communications; the second run was under limited visibility conditions with no VTS communications but with normal bridge-to-bridge and associated communications. Sinus arrhythmia and heart rate were computed for both runs during periods defined as "communications periods" and "noncommunications periods," and are presented in Table 3-3.

TABLE 3-3 MEAN SINUS ARRHYTHMIA (HEART RATE VARIABILITY) FOR SUBJECT 8

Condition	$\bar{x}$*	$\bar{y}$*	n*
Unlimited visibility – VTS communications:			
No communications periods	4.02	64.56	41
Communications periods	2.21	64.64	22
Limited visibility – No VTS communications:			
No communications periods	2.47	64.75	41
Communications periods	2.16	63.85	16

*$\bar{x}$ = mean value of sinus arrhythmia for the number of intervals (*n*) in that condition.
$\bar{y}$ = mean value of heart rate for the same n intervals

In Subject 8, the data indicate that sinus arrhythmia was significantly less during the limited visibility run than during the unlimited visibility run, in an overall sense. The reduction in heart rate variability in the absence of a concomitant elevation in heart rate can be inferred as representing a greater overall workload imposed by the limited visibility condition. It can further be noted that arrhythmia was significantly less during communications than during other periods in the unlimited visibility run, suggesting a greater workload imposed by communications. This difference is not evident in the limited visibility run, which as noted earlier was affected in an overall sense.

Two additional subjects experienced two New York Harbor VTS runs each. One run was under unlimited visibility conditions with normal bridge-to-bridge and associated communications but with no VTS communications. The second run was under limited visibility conditions with VTS communications. Sinus arrhythmia and heart rate were computed for both runs for each subject.

There were five behavioral categories for which sinus arrhythmia measures were computed:

1) Non-run conditions: pre- and post-run
2) General visual activity: consisting mainly of "forward looking" observations
3) VTS communications periods
4) "Other" communications periods
5) Radar display observation and plotting

Mean sinus arrhythmia during VTS communications periods and "other" communication periods are presented for both subjects in Table 3-4. No difference was indicated between "VTS" and "other" communications in sinus arrhythmia implying an equivalent workload in the two conditions. This is noted in both subjects. On the basis of this, "VTS" and "other" communications data were pooled in subsequent analyses.

TABLE 3-4 MEAN SINUS ARRHYTHMIA (HEART RATE VARIABILITY) FOR SUBJECTS 9 AND 10

Subject	Condition	$\bar{x}$*	$\bar{y}$*	n*
9	VTS communications period	2.57	85.00	7
	"Other" communications periods	3.38	83.40	5
10	VTS communications periods	4.22	82.85	12
	"Other" communications periods	5.03	80.64	14

*$\bar{x}$ = mean value of sinus arrhythmia for the number of intervals (n) in that condition

$\bar{y}$ = mean value of heart rate for the same *n* intervals

Sinus arrhythmia and heart rate data for Subjects 9 and 10 are presented in Tables 3-5 and 3-6 respectively. These data indicate several inferences regarding mental workload:

1) There is an overall workload imposed by the task of navigating as indicated by the significant decrease in arrhythmia in run conditions as compared to non-run conditions.
2) Workload is higher during the limited visibility run than the unlimited visibility run as indicated by the significantly lower arrhythmia.
3) It is suggested that communications impose a greater workload on the subject than non-communications (general visual), but this increase might not be significant.
4) The type of communications does not seem to impose differential workloads on the subject.

TABLE 3-5 MEAN SINUS ARRHYTHMIA (HEART RATE VARIABILITY) FOR SUBJECT 9

Condition	$\bar{x}$*	$\bar{y}$*	n*
Unlimited visibility — No VTS communications:			
General visual	3.34	85.86	44
Communications periods	2.98	85.67	12
Limited visibility — VTS communications:			
General visual	2.50	82.92	26
Communications periods	2.77	83.92	13
Radar	2.63	83.09	11
Non-run periods	4.87	80.76	17

*$\bar{x}$ = mean value of sinus arrhythmia for the number of intervals (n) in that condition
$\bar{y}$ = mean value of heart rate for the same n intervals

TABLE 3-6 MEAN SINUS ARRHYTHMIA (HEART RATE VARIABILITY) FOR SUBJECT 10

Condition	$\bar{x}$*	$\bar{y}$*	n*
Unlimited visibility — no VTS communications:			
General visual	5.29	84.78	32
Communications periods	4.87	84.35	17
Limited visibility — VTS communications:			
General visual	4.26	81.88	25
Communications periods	4.65	83.85	26
Non-run periods	6.29	83.38	13

*$\bar{x}$ = mean value of sinus arrhythmia for the number of intervals (n) in that condition
$\bar{y}$ = mean value of heart rate for the same n intervals

CHAPTER 4

IMPLICATIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

The study described in this report was undertaken to measure the extent to which a mariner will react physiologically to the various conditions simulated at CAORF. The CAORF simulator is one of the most technologically sophisticated in existence throughout the world. The maritime conditions simulated at CAORF are taken to be as close a representation of real-world conditions as is technologically possible, at this time.

Validating the realism of the simulation at CAORF is an ongoing concern. Each scenario developed at CAORF is subject to the scrutiny of individuals familiar with the corresponding real-world conditions. Handling characteristics of the ownship model generated at CAORF are evaluated by mariners whose prior experience has been with comparable vessels. Analysis of the mariners on-bridge behavior has been undertaken at CAORF and compared to at-sea on-bridge behavior that occurred in comparable real-world conditions. This analysis revealed a high correlation between CAORF and real-world on-bridge behavior. The information gathered to this point indicates that CAORF simulation is reasonably accurate in reproducing real-world conditions.

One of the primary objectives of the CAORF research program is to develop an assessment of the human factor in a variety of maritime conditions; to determine how the mariner utilizes instrumentation, processes information, and reacts to deal with the particular conditions he is faced with. An understanding of the human element in maritime conditions is crucial to determining the factors relevant to collision avoidance, safe maneuverability through a particularly demanding channel, establishing safety standards for a particular port, etc.

The measurement of physiological reactions in mariners addresses both the concerns of validating CAORF simulation and assessing the human factor in maritime problems. First, it serves as a means of validating the realism of CAORF simulation. There are certain maritime conditions, i.e. collision avoidance problems or extreme environmental conditions such as strong wind or current, either of which would logically be expected to place significant demands on the navigator of a vessel. There are in fact numerous informal reports from ships' masters that under certain conditions, "I really feel my heart beating" or "I really sweat through an experience like that." If these reactions occur in the real world, will they occur if a mariner is exposed to comparable conditions at CAORF? Measuring the on-going physiological state of the master while he performs his duties on the bridge at CAORF is the most direct means of addressing the validity of CAORF

simulation. Will the ship's master react physiologically in a manner consistent with the demands of the navigation problem he is faced with? Are the physiological reactions of the master on the CAORF bridge comparable to those of masters in the analogous real-world conditions? These questions were addressed in part by this study.

Measuring the physiological state of the mariner is one of the most scientifically sound means of human factor assessment. The maneuvering of a vessel through a navigation problem is a function of several factors, the ship itself and its hydrodynamic characteristics, the environmental conditions of wind and current, the instrumentation available to the mariner providing information about ownship and traffic ship progress, and finally the mariner himself. The mariner, the human element, is the most complicated, most variable, and most difficult component to assess and to understand. Prior to the present study, a number of behavioral assessment techniques have been employed at CAORF to assess the human factor in maritime problems. These techniques have provided valuable information, but they fall short to a certain extent since they do not assess the mariner directly but rather assess his behavior. By measuring and assessing the behavior of a mariner, it is possible to draw inferences about his psychological and emotional states which give rise to the behavior. These, however, are only inferences and as such they provide an equivocal assessment of the "state" of the mariner. However, if the behavioral data are augmented by and integrated with a direct measurement of the corresponding physiological activity of the individual, the accuracy of assessment of the state of the mariner improves considerably.

The data from physiological monitoring could prove invaluable in understanding the factors influencing the outcome in certain maritime problems, ship encounters, docking and port entrance and egress, maneuvering through severe weather conditions, etc. What is the state of the mariner under certain conditions? Are certain conditions stressful? Is a stress state in the mariner a necessary component of reacting to certain maritime problems, or should stress be mitigated in a mariner by providing new and more sophisticated instrumentation so he can carry out his duties more efficiently? These questions can be addressed if some direct assessment of the mariner is made—a physiological assessment. These questions were addressed in part by this study.

The data amassed in this study have provided information necessary to draw certain important conclusions. First, it is clear that the simulated conditions employed in this study were realistic representations of real-world conditions and furthermore that they were reacted to by mariners as one would expect in comparable real-world conditions. It was found, in the collision avoidance problems, that at critical ship encounters, the physiological reactions of the masters were those best characterized as reactions to threat changes within the context of the scenario. It further was clearly indicated that these reactions varied directly with the changing demands of the problem. During low demand points in the problem, there were no reactions, while during high demand points, the physiological measurements revealed aroused states in the masters. When the demand decreased in the problem, i.e. the threat of collision passed, the masters' physiological state returned to a baseline level.

It must be pointed out that these reactions did not occur in every subject tested, but in those subjects in which it did occur (2 out of 3) it occurred in every problem in which they were

tested. That one subject did not react with "physiological responses" during collision avoidance problems points to the fact of individual differences. Certain individuals are less reactive than others: this is to be expected. The fact that individual differences (i.e., physical conditioning, etc.) were noted among the masters further confirms the realism of CAORF simulation. Such individual differences should also be manifested in real-world circumstances.

In non-collision avoidance problems examined in this study, the physiological state of the mariners were for the most part at non-aroused levels. It was indicated, however, that in the CAORF New York Harbor scenario, a number of subjects manifested a heightened physiological state at a particular point in the scenario, the Bergen Point-Bayonne Bridge and Draw area. These results further confirm the realism of CAORF simulation. These are reported by New York-Sandy Hook pilots to be particularly difficult to navigate. The physiological reaction recorded during simulation runs. through these areas confirm that the mariners were in fact experiencing difficulty at these points. These results are of particular importance since they indicate that variations in physiological state of the mariners measurable under non-extremis as well as extremis conditions. This implies that the measurement of the physiological state of the mariners can be usefully applied to a variety of conditions studied at CAORF and not limited to extreme conditions.

A second major finding of this study was that the monitoring of the physiological state of the mariner provides a means of assessing what appear to be variations in the mental workload. This inference stems from the sinus arrhythmia data collected in the New York Harbor-VTS phase of the study. Sinus arrhythmia variations were clearly discernible between different conditions which could logically be inferred to impose different workload demands on the mariner, i.e., navigating in limited versus unlimited visibility conditions. These data contribute to affirming the realism of CAORF simulation and they also point to a second, and potentially valuable, application of physiological monitoring at CAORF, the assessment of variations in workload demands on the mariner.

In summary, the monitoring of heart rate patterns of mariners at CAORF revealed:

1) Ship encounters producing a collision avoidance problem produce an arousal physiological/emotional state in the mariner. The reaction of the mariner mirrors well the development of the collision avoidance problem and diminishes with the passing of the problem.

2) Not all mariners react in the same way to a collision avoidance problem, in terms of their physiological reactivity. Furthermore, differences in reactivity between mariners exposed to the same collision avoidance problems may reflect either individual differences, differences in abilities as mariners, differences in the sophistication of the navigation equipment provided to the mariners, or some interaction of all of these factors.

3) Variations in sinus arrhythmia appear to be useful in differentiating cognitive processing demands placed on the mariner. Navigating under limited visibility was shown to be significantly more demanding in a workload sense than navigating the same course under limited visibility.

4.2 RECOMMENDATIONS

Several directions for future research are suggested by these data. First, to validate the realism of CAORF simulation further, it would be desirable to collect physiological data under real-world conditions. These real-world conditions could then be duplicated at CAORF with physiological monitoring carried out. If the physiological measures correlate well between the two conditions it would provide very substantial support for the validity of CAORF simulation and of the use of physiological measurements.

Further work is suggested on collision avoidance problems, since they are of major concern to the maritime industry. By monitoring the physiological state of the mariner throughout a collision avoidance problem key points of reactivity can be determined to gain some insight into what is informing the mariner of the threat of collision. What information is the mariner relying on? Is the stress reaction in the mariner a critical element in affecting his reaction to a collision avoidance problem? Can certain instrumentation be provided to the mariner to aid in solving collision avoidance problems and will the availability of such instrumentation reduce the level of stress manifested by the mariner in the face of a collision avoidance problem? Is a reduction of stress in a mariner desirable for dealing with collision avoidance problems or is it an integral element? Is there some optimal level of physiological arousal in which a mariner functions best? These questions can be addressed given a means to assess the physiological state of the mariner.

A means of assessing the navigational demands of a harbor or channel, etc., is provided by physiological monitoring. A comparison study may be carried out to assess a variety of ports and/or channels to rank them as to physiological impact on the mariner. More importantly perhaps, a proposed port may be evaluated prior to construction and features of it may be altered and modified so that it is less physiologically demanding on the mariner.

At CAORF, physiological monitoring of subjects can be used to equate or grade scenarios as to their relative workload demand on the subject. By monitoring physiological as well as behavioral reactions, one can determine the extent of stress elicited by a certain navigation problem and compare it to that of others.

Physiological monitoring may be employed to assess the effects of training procedures. Are ship's personnel less physiologically reactive to certain problems posed to them after they have undergone a training program as compared to their reactivity before training?

The usefulness of physiological data in assessing variations in cognitive processing demands on mariners opens a vast field of research at CAORF. One might investigate the effects of high and prolonged workload demands on a mariner's navigation performance. An obvious area of research would be to study instrumentation to determine how the workload of a mariner is affected by providing new instrumentation, providing the most efficient displays or witholding superfluous information from the mariner.

The major contribution of the present study to the direction of future research activities at CAORF is that it provides a new means of assessing the mariner in maritime situations. It indicates that physiological monitoring of maritime personnel is feasible and, more im-

portantly informative. It suggests insights into the activity of a mariner in a variety of maritime conditions that are unobtainable through other available means. The present study suggests that physiological monitoring be undertaken at CAORF in a variety of further efforts particularly those which may involve stress in the mariner. This study also suggests further development of physiological measures at CAORF. Currently, heart rate monitoring is being pursued. A potentially more sensitive physiological measure is skin resistance. The development of this measure should be pursued.

Physiological assessment should be considered as one of the components of a multi-factor (physiological, perceptual, cognitive, behavioral) index to elucidate the role of the human factor in maritime problems.

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